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Natural Gas to BTX

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The goal of this project was to design a process to produce 1B pounds of benzene, toluene, and xylene (BTX) per year in an unspecified ratio using a ZSM-5 catalyst in accordance with US Patent 8,278,237. Our process will be located in the Gulf of Mexico and will produce primarily benzene and a small amount of paraxylene for the purposes of selling to industrial clients. In this report, we present a design that yields 1.1B lb/yr of benzene with a purity of 97 mol% and 33 MM lb/yr of paraxylene with a purity of 99.8 mol% as the primary products. Additionally, 400 MM lb/yr of naphthalene with a purity of 99.7 mol% is produced as a byproduct. Due to the scale of this assignment, this process involves the heavy use of utilities, especially electricity and cooling water. The process requires $347 MM in total capital investment. Despite this, the process we present has an NPV of $285MM and an ROI of 28.4% after the third year. It should be noted that our process produces 673,000 tons of CO_2 per year. Based on the ROI and NPV of this process, we recommend that management proceed with plans to bring our process into operation while increasing efforts to further research the catalyst and market dynamics.

Disciplines
Biochemical and Biomolecular Engineering | Chemical Engineering | Engineering

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Chemical and Biomolecular Engineering | Chemical Engineering | Engineering

Department of Chemical & Biomolecular Engineering

Senior Design Reports (CBE)

University of Pennsylvania *April 2015*

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University of Pennsylvania

CBE 459: PROCESS SYSTEM DESIGN PROJECTS

Professors Leonard Fabiano and Warren Seider

Natural Gas to BTX

Senior Design Project

Bruce Chanenchuk, Alexander Evans, Sandhya Thiyagarajan

April 2015

Department of Chemical and Biomolecular Engineering

University of Pennsylvania

Faculty Advisor: Dr. Wen K. Shieh, University of Pennsylvania

Professor Leonard Fabiano, University of Pennsylvania

Project Author: Mr. Bruce Vrana, DuPont Engineering Research & Technology

University of Pennsylvania
School of Engineering and Applied Science
Chemical and Biomolecular Engineering April 2015

Dear Dr. Shieh, Professor Fabiano, and Mr. Vrana,

As requested by our assigned Senior Design Project, we have designed and evaluated a process for the production of one billion pounds per hour of benzene, toluene, and xylene (BTX) products on the Gulf Coast. The process uses a ZSM-5 catalyst specified by U.S. Patent 8,278,237 issued to Shinichi Yamada in 2012. The overall process produces product streams of benzene, paraxylene, naphthalene, and a purge stream with high heating value. The process consists of four sections: A dehydrocyclization reaction, a BTX separation train, an alkylation process, and a furnace section.

This report provides a detailed process and profitability analysis of the proposed plant. A natural gas feed of 639,403 lb/hr is required, as well as a methanol feed of 2243 lb/hr. Production was assumed to be 24 hours a day for 330 days a year. The major product is benzene, of which 1.1B pounds is produced per year.

Rigorous profitability analysis was conducted in order to project cash flows for fifteen years. The total capital investment of the plant is $347MM and the expected NPV of the project is $285MM. The estimated IRR of the project is 30.92% and the 3-year ROI is 28.4%. Our recommendation is to go forward in production using the outlined process, but to continue research in the areas of market pricing projections as well as catalyst performance.

Sincerely,

Bruce Chanenchuk | Alexander Evans | Sandhya Thiyagarajan

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INTRODUCTION

Abstract

The primary objective of this project was to design a process to produce 1B pounds of benzene, toluene, and xylene (BTX) per year in an unspecified ratio using a ZSM-5 catalyst in accordance with US Patent 8,278,237. Our process will be located in the Gulf of Mexico and will produce primarily benzene and paraxylene for the purposes of selling to industrial clients. In this report, we present a design that yields 1.1B lb/yr of benzene with a purity of 97 mol% and 33 MM lb/yr of paraxylene with a purity of 99.8 mol% as the main products as well as 400 MM lb/yr of naphthalene with a purity of 99.7 mol% as a byproduct. Due to the scale of this assignment, this process involves the heavy use of utilities, especially electricity and cooling water. $347 MM in total capital investment is required. Despite this, the process we present has an NPV of $285MM and an ROI of 28.4% after the third year. Based on the ROI and NPV of this process, we recommend that management proceed with plans to bring our process into operation while expending significant effort into additional research regarding the catalyst performance on an industrial scale as well as market dynamics.

Objective Time Chart

The goal of this project was to design a process that created 1 B lb/yr of BTX. The scope of this project included designing the process from input to product storage, documenting mass & energy balances, calculating utility consumption, and determining the financial feasibility of the plant. Project leaders for this effort were Bruce Chanenchuk, Alexander Evans, and Sandhya Thiyagarajan. A deliverable timeline for the process is as follows:

Deliverable	Description	Date Accomplished
Mass Balance and Basic Process Design	Process developed using various patents to produce 1 B lb/yr of BTX. Decisions made for separation sequence as well as alkylation.	February 3rd
Energy Balance and Equipment Designed	Heat Exchangers and Process Equipment added to help determine feasibility of process. Equipment sizing is also started.	March 17th
Utility Requirements Determined	Equipment sizing completed and utilities for heating and cooling were determined. Furnace section added to help reduce importing heating utilities.	March 31st
Financial Analysis Completed	NPV and ROI determined. Sensitivity analysis completed to determine factors that affect profitability.	April 5th
Report Completed		April 13th

Project Charter

BTX is a petrochemical mixture used to make products such as styrenes, polyesters, and gasoline components. Individually, benzene is typically used in plastic and resin productions, toluene is predominantly used as a solvent or to increase the octane ratings in gasoline fuels, and xylene is typically used for rubber and leather industries. Paraxylene, the most valuable xylene isomer, is used in polyester clothing and plastics. BTX is currently produced by reforming crude oil or cracked naphthalene feeds. The use of these sources, particularly crude oil, has been decreasing due to the economic and environmental risks they pose. Instead, the industry is turning to a natural gas feed.

An increase in shale gas production has created an emerging market demand for natural gas, a cheaper energy source than crude oil. Even with the 2015 drop in crude oil prices, prices are still 2.5 times more expensive than natural gas per MMBTU. Additionally, natural gas provides up to 330% more BTUs/USD than crude oil, making it a more financially appealing feed [3].

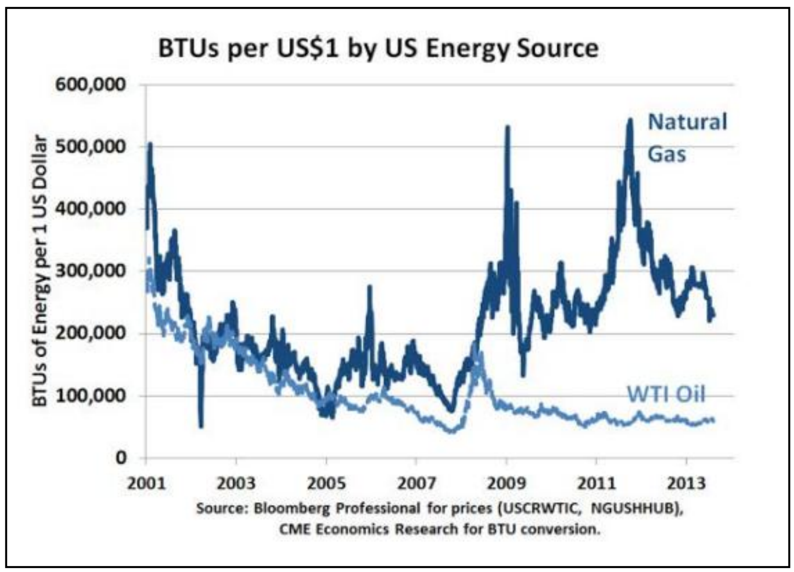

Figure 1: Natural Gas vs. Oil in the Market [4]

Furthermore, crude oil is known to have a higher level of greenhouse gas emissions than natural gas. Natural gas is an abundant domestic resource, and provides the source for the production of one billion pounds of BTX in this report. With natural gas production burgeoning due to hydraulic fracturing and horizontal drilling, determining a way to produce a BTX mix from natural gas is a promising step for the specialty chemicals industry. As of 2010, global consumption of benzene alone was 40 million tons. The market for BTX is extremely large, so economically optimizing the production of BTX by using a natural gas feed is a worthwhile investment [14].

Natural gas poses a more environmentally and economically viable source for BTX production by reducing greenhouse gas emission and reducing dependence on foreign crude oil. Additionally, the market for BTX is large enough to justify shifting resources to natural gas reformation.

Innovation Map

This project is motivated by the economic and environmental benefits of BTX produced from natural gas as an alternative to crude oil. Economic motivation exists due to the price of natural gas compared to crude oil. Natural gas production will help drive down the cost of BTX. Production of BTX from domestically-sourced natural gas will help reduce cost of the process by reducing international dependence on crude oil. Finally, gulf coast production of BTX is fairly cheap domestically, especially since sources of natural gas such as the Barnett and Eagleford shale plays are close by. The technological motivation behind the process is the catalyzed dehydrocyclization process, which occurs in a fixed bed reactor.

Innovation Map

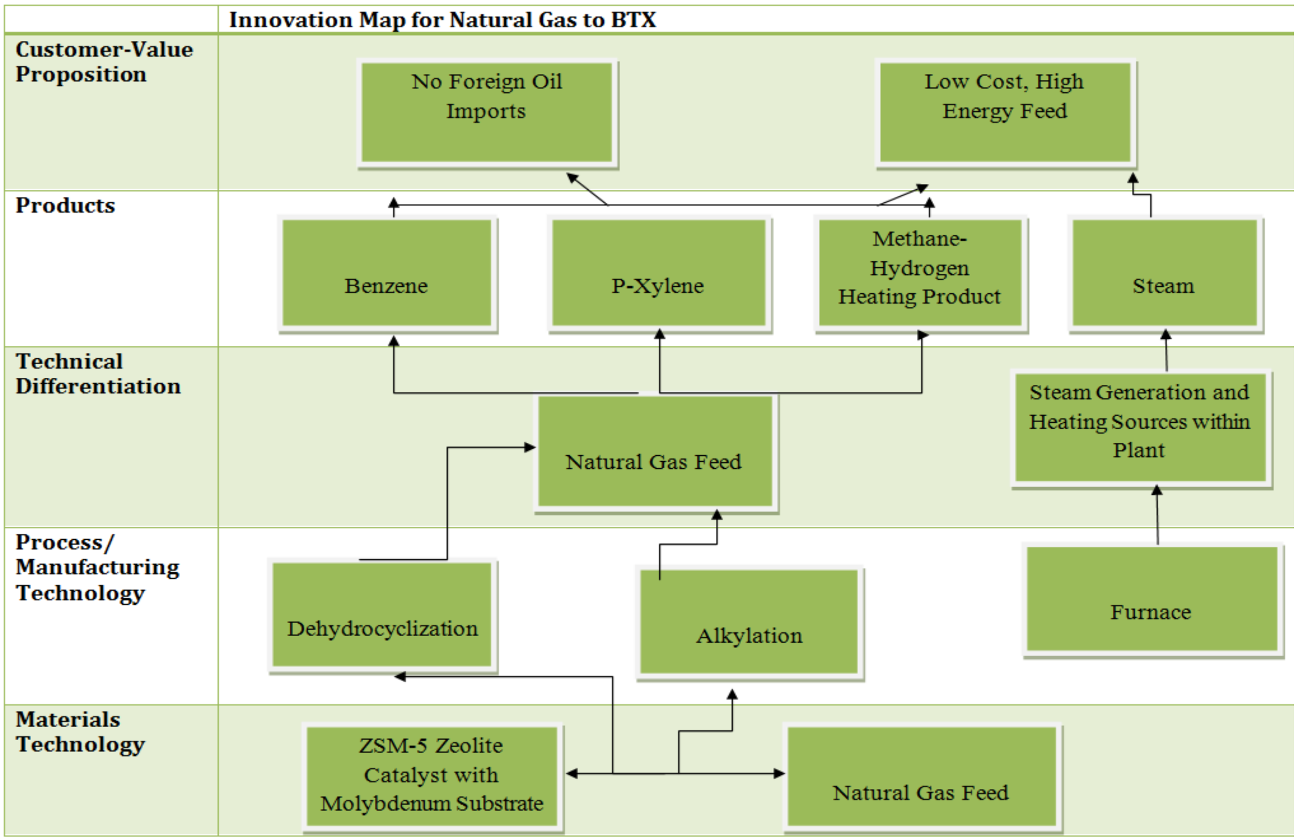

Figure 2: Innovation Map

MARKET AND COMPETITIVE ANALYSIS

Market & Competitive Analysis

Natural Gas

Since the innovation of hydraulic fracturing technology, natural gas has become more readily available in the United States. Because of this increased supply, the price of natural gas has stayed significantly below oil prices following the crash of both commodities during the financial crisis. Because of this large spread between oil prices and natural gas, many technologies have attempted to harness natural gas for purposes that previously relied on oil. BTX has traditionally been extracted from naphtha in petroleum refineries using a catalytic reformer. Due to the relative price advantage of using natural gas as a feedstock, this project explores a new method to produce BTX using natural gas.

However, a drop in oil prices in recent months has led to uncertainty in the oil, gas, and petrochemical industries. Oil prices have dropped almost 50% over the past year, causing a ripple-effect across a variety of industries. While natural gas prices have dropped as well, they have not fallen as much relative to oil prices, leading to a tightening of the spread. This phenomenon is unfavorable for our project as the decrease in oil prices reduces the costs of existing BTX production processes while lowering our costs by a lesser magnitude. Additionally, BTX prices, which show strong correlation to oil prices, have also fallen significantly over the past several months. This will make our process less profitable as our revenues will decrease while our capital costs remain the same [8].

Benzene

Benzene is used in the petrochemical industry to build larger hydrocarbons such as styrene and cumene. It is also added to gasoline due to its high octane value. Various derivatives of Benzene can be found in Figure 3 below. Benzene prices correlate strongly with

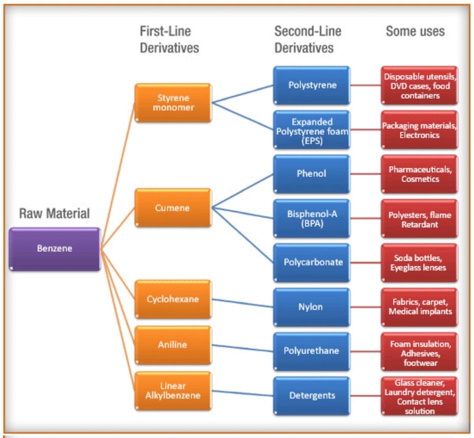

Figure 3: Derivatives of Benzene [14]

crude oil prices and also rely on the demand for benzene derivatives, such as styrene and cumene. As shown in Figure 4, the capacity utilization rate for benzene production has been steadily rising since 2009 and analysts from ICIS expect this trend to continue, at least through 2019. This is favorable for our plant as it could provide additional production to capture the increasing demand [9].

Toluene

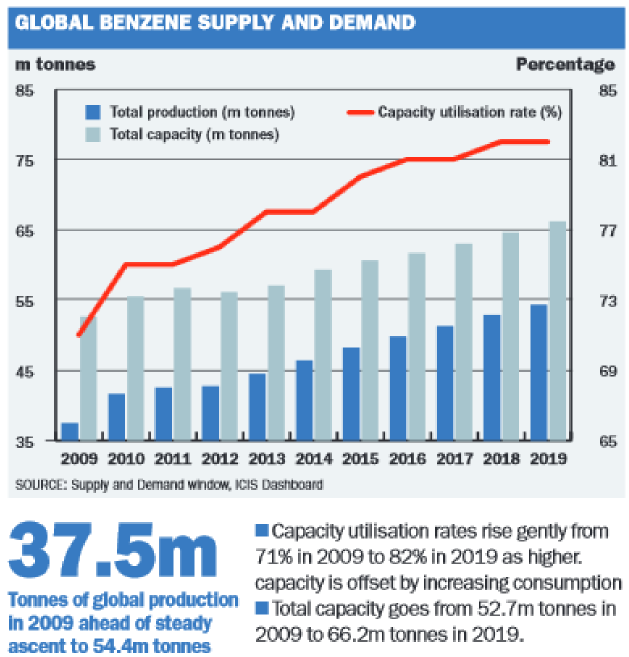

Figure 4: Supply and Demand of Benzene [8]

Like benzene, toluene prices are strongly correlated with that of crude oil. Toluene is primarily used to produce benzene and xylenes. In addition, it is used early in the polyurethane production process, as a solvent in paint thinner, and to increase the octane levels of gasoline.

Paraxylene

Paraxylene is the most valuable of the three xylene isomers due to its para configuration, lending to easy polymer creation. PX is used mainly in the production of polyethylene terephthalate (PET), which is used to produce fibers and films. Like the other BTX constituents, paraxylene correlates with crude oil prices but also strongly depends on the demand for PET [16].

Petrochemical Industry

BTX is included in the petrochemical industry with Benzene representing 11% and Toluene representing 6% of the $89.6 billion dollar industry [8]. Key economic drivers for the industry include the demand for resin and plastic manufacturing as well as the prices of crude oil and natural gas. Currently, the market has a medium saturation level with major players including: Exxon Mobil, LyondellBasell, Royal Dutch Shell, and Chevron Corporation. IBISWorld expect the growth rate of the industry to increase 3.5% over the next five years, rebounding from its down year in 2014. The major market segmentation can be seen in Figure 5 above.

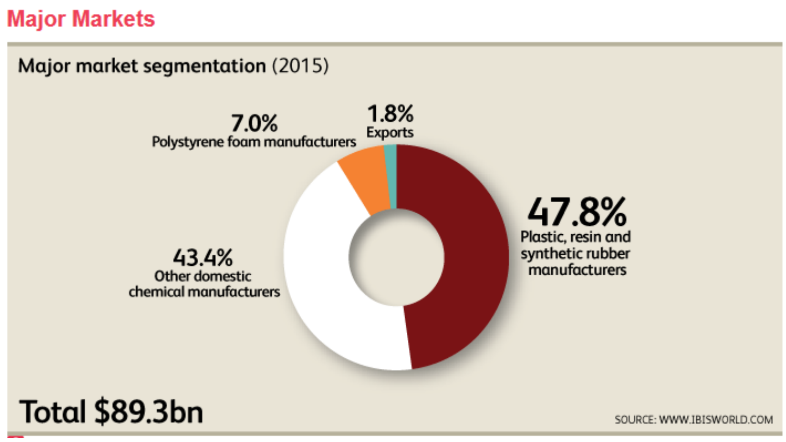

Figure 5: Major Markets for Petrochemical Production [8]

Major Competition

Exxon Mobil:

ExxonMobil holds a 15.5% market share in petrochemical manufacturing. A Texas based company, Exxon revenue has grown at a 9.0% rate each year, only dipping when the demand for chemicals changed. Industry experts saw a 0.3% increase in revenue for 2014 year. Exxon Mobil produces 0.9MM metric tons per year of paraxylene. Our proposed plant will only produce 0.0165MM tons of paraxylene per year. As such this is only 2% of the Exxon Mobil capacity so we do not see a large issue capturing a small market share that we need in order to enter the paraxylene market [5].

LyondellBasell:

LyondellBasell has a 9.3% market share in the petrochemical industry and has invested 1.2 billion dollars in 2014 to increase petrochemical production. This has caused their revenue to skyrocket to 9.2 billion dollars. The company produces 195MM gallons of benzene per year. Our proposed plant produces 186MM gallons of benzene per year, so we would need to capture a major portion of the market share in order to be successful. Because of this, it would be important to partner with an end user of benzene, such as a major styrene producer. However, this may prove difficult as most of the major U.S. styrene producers (LyondellBasell, Dow Chemical, Shell, Chevron) are vertically integrated and produce their own benzene in-house [11].

Customer Requirements

The required amount of BTX production for this plant is 1B lb/yr. Benzene purity is required to be at least 95%, with the contingency that the impurities are primarily aromatics [1]. According to GTC technology, paraxylene purity is required to be 99.8% for customer use.

Naphthalene purity should be 95% - 99.9%, depending on customer use [6, 9]. The separated products from our process meet these purity requirements. A purged stream consisting of 17% hydrogen will also be sold for its heating value. This will be sold at its heating value, using the same ratio as the natural gas feed.

PROCESS OVERVIEW, FLOW SHEETS, MASS & ENERGY BALANCES

Preliminary Process Synthesis

The first stage of our process is to convert the CH_4 contained in natural gas to aromatic products, specifically B, T, X, and N. This conversion is accomplished using a zeolite catalyst, patented under US Patent 8,278,237. The catalyst is reacted with a silane compound larger than the pore size of the catalyst and with an amino group capable of reacting with the zeolite at a Bronsted acid point. The substrate is then loaded with copper and molybdenum, within a range of from 2 to 12 wt. % based on total amount of the calcined catalyst. Copper is loaded at a copper to molybdenum molar ratio of 0.01 to 0.8. The catalyst is reacted in the presence of carbonic acid in a fixed bed to produce favorable conversion rates of methane. The catalyst in US '237 has the highest conversion when the level of carbonic acid is near 3% by volume, which is fortunately very close to the levels present in natural gas. Therefore, the catalyst would require minimal to no additional CO_2 feed stock. As we developed our model, we were able to maintain a CO_2 level close to 4%, so no additional CO_2 feed is needed to maintain the cited level of CH_4 conversion for our process.

This catalyst was presented to our team at the beginning of the project, but other catalysts were explored to find the optimum strategy to produce the desired aromatics, since US '237 did not contain complete information regarding the yields of products other than total BTX, N, and carbon coke. Specifically, the ratio of T and X was not given in the '237 patent, which was vital to know since the most valuable product in our project per pound is paraxylene. The missing information needed to be found to complete an accurate mass balance and reactor simulation, so patents with similar catalysts were researched. One of the patents explored was a patent filed by the Universidad De Zaragoza which gave more complete information regarding the yields of all products. This patent (US Patent 8,697,926) was very complete and illustrated high conversions of the feedstock, both with a fluidized bed and a fixed bed. In most cases, fluidized beds give better conversion of the feedstock due to the uniform particle and temperature distributions inside the fluidized reactor. In the experiment in US‘237 using a fluidized bed, the selectivity to BTX products as well as the conversion of methane feed were excellent (98.9% and 12.45%, respectively). However, the improvements in selectivity to BTX could not be compared to US ‘237 since these values were not reported in US ‘237. US ‘926 has a feed conversion of 12.45%, where US ‘237 has a conversion of 12.4%. Finally, the fluidized bed in US ‘926 shows a maximum conversion of 12.99%, for an improvement of 0.54% over the fixed bed using the same catalyst. Despite this improvement in conversion, a fluidized bed would require significant additional pumping utilities and a larger vessel size, the costs of which are not outweighed by additional revenues as a result of the increased conversion of the catalyst.

After the selection of the catalyst was made, the next major design challenge we faced was a relatively low conversion of the feedstock. We needed to recycle as much of the unreacted methane as we could without recycling too many of the gaseous products, such as H_2. Our first intuition was to simply recycle a portion of the reactor effluent and purge a small fraction of the stream; however we encountered a problem due to the high formation rate of H_2 as a side product of the produced aromatics. The following reactions take place as part of the overall process:

1. $6CH_4 \rightarrow C_6H_6 + 9H_2$
2. $7CH_4 \rightarrow C_7H_8 + 10H_2$
3. $8CH_4 \rightarrow C_8H_{10} + 11H_2$
4. $10CH_4 \rightarrow C_{10}H_8 + 16H_2$
5. $3CH_4 + 2CO_2 \rightarrow C + 2CO + 4H_2$

According to the above reactions, for every 34 moles of CH_4 that react, 50 moles of H_2 are formed. As a result, the effluent stream of the dehydrocyclization reactor contained over

5,000 moles of H_2 produced per hour (17 mol% of the effluent) that needed to be removed from the process loop. After consulting with professional engineers, we first explored the use of a cryogenic condensing system to condense the unreacted methane so that it may be isolated and recycled. Since this method involved heavy use of utilities and intricate systems of cryogenics, we decided to explore the use of a PRISM Membrane system instead, which is used in industry to remove H_2 from gaseous streams via membrane separation.

The PRISM unit operates at 600 psig, which is well above the pressure in the vapor stream exiting the flash vessel, which is at 28 psig. Due to this high differential in pressure, six 30,500 hp compressors would be required to achieve the required pressure for such the stream, which has a volumetric flow rate of 13 MM ft^3 per hour. A further problem with the PRISM membrane unit was the capital cost. Estimates given by engineers at Air Products and Chemicals, Inc. suggested that a PRISM unit for our process would cost around $180 million [Appendix E]. This is obviously an enormous capital cost and would have contributed to over half of our total capital investments.

Lastly, a PRISM unit suited for our process would only be able to remove a maximum of 85 mol% of the H_2 present in the vapor stream of the flash vessel with a resulting purity of 44 mol%. This of course means that the balance would be made up by the other molecules in the stream that we did not necessarily want to separate, such as CH_4 and CO_2. To determine the resulting ratios of the other molecules in the stream containing 44% H_2, we assumed that all of the other molecules would appear on the other side of the membrane in the same proportions that they appear exiting the flash. This means that if benzene was twice as prevalent as toluene before reaching the PRISM unit, we assumed it would be twice as prevalent as toluene in the stream after passing through the PRISM membrane. This allowed us to simulate the PRISM membrane by sending the same fraction of each component other than H_2 across the membrane. After performing this calculation, it was found that the required fraction of each of the other components to send across the membrane was 21 mol%. Since a stream containing 44% H_2 cannot be marketed as a "Hydrogen stream," this meant that we would effectively be losing 21% of our CH_4 on every pass through the reactor.

In exploring the options to recycle as much CH_4 as we possibly could, we ultimately decided on the simplest option. Since the reaction taking place in the dehydrocyclization reactor produces around 5,000 moles of H_2 per hour, we would be required to purge around 20% of our vapor stream from the flash vessel in order to allow H_2 to escape the system. This of course means that we would also purge 20% of all other components present in the stream, most significantly of which is the unreacted CH_4. While this purge fraction is many times larger than a standard purge stream, it is still less than we would be purging using the PRISM system, which required 21% of CH_4 to be purged. Also, we can use the purge stream for heating value to fuel our other units in the process. In this case, the simplest option turned out to be the best one.

After the aromatic products are made in the dehydrocyclization section, the next part of designing the process involved deciding whether or not to separate the B, T, X, and N products. This decision hinged on whether or not it would be worth it to achieve pure products for the extra capital costs involved in purchasing the equipment to do so. Due to the scale of our process, we decided quickly that separating the BTX products into individual components would produce the most profit. If we were not producing as large of a quantity of BTX, it might not be worth the investments to separate the products. Additionally, to meet the industry requirements for a "BTX" stream of 48 mol% benzene, a portion of the benzene would need to be separated regardless [1]. Thus, the decision was made to separate all products and focus on paraxylene production, the most valuable product.

Once this decision had been made, we next had to decide on how to perform the separation. This portion of the process was designed to minimize the required capital investments. The bottoms product of the flash separator (COL-101) yields a liquid stream of B, T, X, N, and some small amounts of absorbed gases. To accomplish the separation, we decided to design a direct sequence which would separate B in the first column, T in the next, then X and N in the last. This decision was made so that the temperatures of the columns would increase progressively. In doing so, we set up a system where the highest flow rate flows through the first column, which has the lowest operating temperature, while the lowest flow rate flows through the column with the highest temperature. In an indirect sequence, the higher flow rate would experience the highest operating temperature first, which would require additional utilities to achieve the same separation. Furthermore, we designed the columns to operate near atmospheric conditions so that they can operate at the lowest possible temperatures and thus use the smallest amount of heating utilities.

After the third column in our separation process, the distillate exiting the column contained approximately 91.2 mol% of paraxylene, which is not pure enough to sell to processes that are using paraxylene as a feedstock for polymerization. To achieve the required purity (customer requirements call for 99.8 mol %), the only method that is suitable is crystallization. The similar boiling points of paraxylene, metaxylene, and orthoxylene (281 F, 282 F, and 291 F, respectively) lead to difficulty when attempting to separate the three components by ordinary distillation methods. The crystallization methods rely on the larger differences in melting points of the three species, which are much larger than that of the boiling points. Paraxylene melts at around 55 F, which is 68 F higher than the next highest of the three, orthoxylene at -13 F. The crystallization method we chose to use operates at the melting point of orthoxylene. After the feed stock is crystallized, it is sent to a filtration and purification unit where it is washed and a nearly-pure paraxylene stream is obtained. These units, while relatively energy-intensive, are required to be able to market paraxylene as a product of our process.

After deciding to separate our aromatic products into B, T, X, and N streams, we then turned our attention to our toluene stream. It is possible to alkylate benzene and toluene further to higher aromatic products, which has advantages since PX is the most valuable aromatic product in our process. Toluene is the primary concern of this section, since it is the least valuable product. Since we separate benzene upstream of toluene, we desired a reaction that would convert as much toluene as possible into PX. We began our search for patents for an alkylation reaction using methanol as the alkylating agent since this is common practice in industry.

At first, all of the patents found online used a large excess of methanol relative to toluene, which was undesirable for our process since we needed a small amount of fresh feed in order to make alkylation profitable. Furthermore, reacting with excess toluene would allow for higher yields of paraxylene rather than higher products. We found US Patent 6,642,426 for a fluidized bed with a vapor phase alkylation reaction with staged injection of alkylating agents, which uses a molar ratio of toluene to methanol of 1.8. With this ratio, we are able to make our process of alkylating toluene more profitable than simply selling a toluene stream. While the fluidized bed is more expensive than a fixed bed reactor for the same mass of catalyst, our revenues are on a large enough scale to warrant extra expenses such as a fluidized bed reactor. US ‘426 also shows excellent selectivity to paraxylene. The only drawback to using a reactor with excess toluene is that it is difficult to attain high conversions, but this is not an issue for our process since we can simply recycle any BTX back into our separation train. US ‘426 shows a toluene conversion of around 35%, which is more than high enough to warrant this additional reaction in our process.

After the vapor exits the reactor bed, the aromatic products must be separated from the unreacted methanol and water product. The first method we chose to explore involved using distillation columns to separate methanol and water (referred to as the aqueous phase) from the BTX phase (referred to as the aromatic phase). However, this separation, which involved two distillation columns, recycled too much water and methanol into our BTX separation train. In order to keep the methanol and water inside the alkylation loop, a better separation was required. After generating several phase diagrams for the aromatic and aqueous mixture, we realized that we could achieve an excellent separation using one decanter unit. This unit gives us an aromatic stream that contains only 8 mol% water and methanol, which is an acceptable fraction for our process. The aqueous phase is recycled back to the feed to the reactor, and the aromatic phase is fed back into COL-201. To maximize the revenue gains from this alkylation reaction, as much of the toluene as possible is sent to the reactor, leaving next to no toluene to sell as a product stream. This was the goal of the alkylation, leaving only B, X, and N as our product streams.

Assembly of Database

Transport and Thermodynamic Data

All transport and thermodynamic data was pulled from Aspen Plus V8.6 Model. For all blocks except the decanter, the Soave Redlich Kwong thermodynamic method was used. For the Decanter, the NRTL thermodynamic model was used.

Pricing Data

Consumer Compounds

Table 1: Consumer Compounds

Compound	Lb/yr	Price per Gallon	Density (lb/gal)	Price Per Pound
Benzene	$1.09*10^9$	4.50	7.73	$0.62
P-Xylene	$3.29*10^7$	5.05	7.21	$0.70
Naphthalene	$3.95*10^8$	3.82	9.55	$0.40

Heating Products

Table 2: Heating Products

Compound	lb/yr	BTU	Price per MMBTU (USD)
Methane-Hydrogen Product for Heating	254,930	$4.04*10^{12}$	$4

Table 3: Materials Costs

Material	Amount Needed	Cost
Natural Gas	$6.39*10^5$ lb/hr	$4.00/MSCF
Catalyst	385,272 kg/yr	$30.00/kg
Methanol	2243 lb/hr	$0.19/lb

Safety and MSDS

Major safety concerns for this plant include highly flammable materials at high temperatures, as well as a significant amount of CO_2 emitted, which is an environmental safety concern. MSDSs for any hazardous chemicals or products are listed in the Appendix C. Safety precautions will be outlined to all operators and engineering staff involved in production.

Process Flowsheet and Material Balances

The process flowsheet for the plant has been divided into four sections for easy reading. Following each process flow sheet, an overall mass and energy balance and stream report for the section is included.

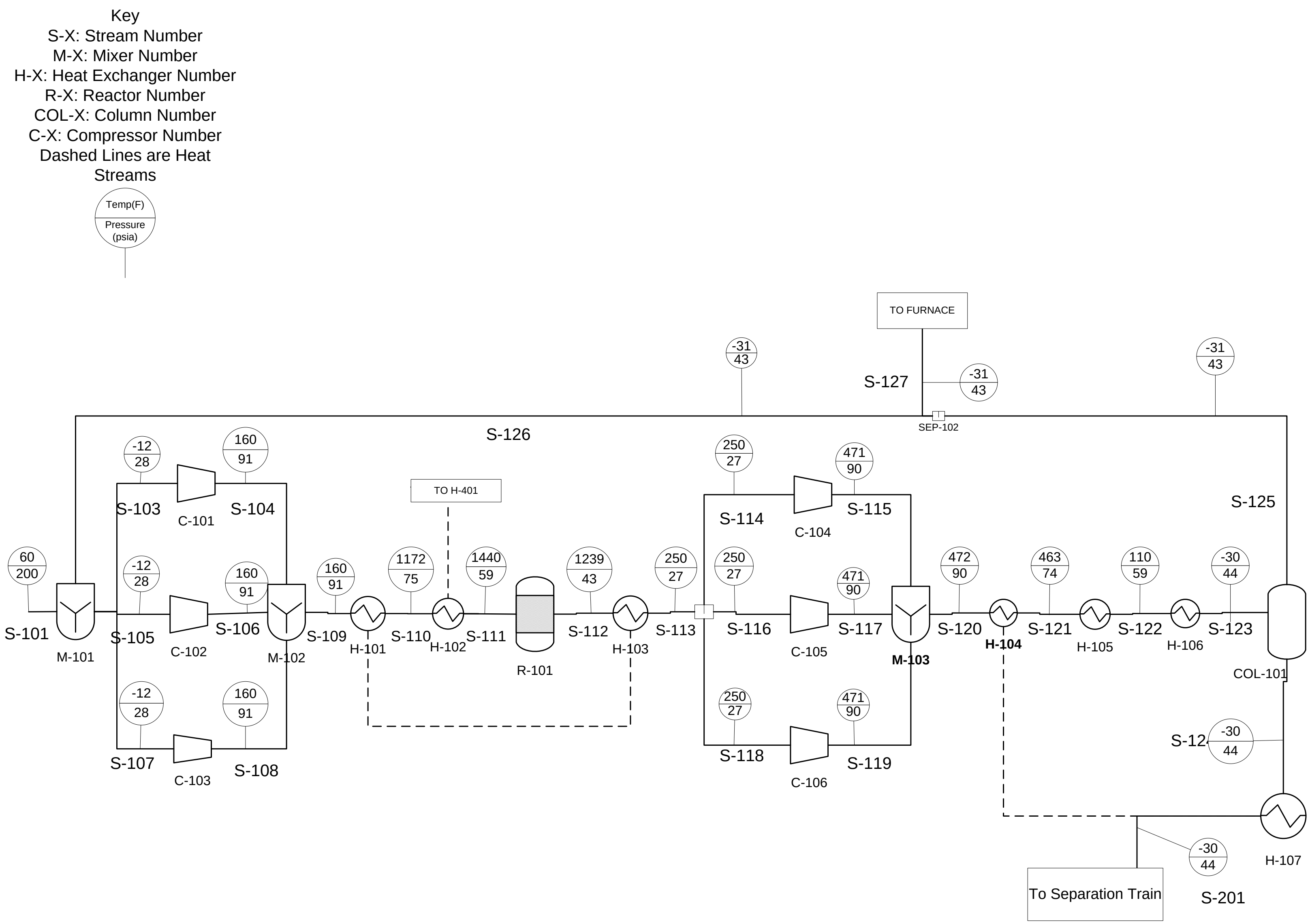

Figure 6: Process Flow Diagram for Dehydrocyclization

Overall Mass & Energy Balance:

Table 4: Overall Mass & Energy Balance for Dehydrocyclization

	S-101	S-127	S-201
Stream Type	Inlet	Outlet	Outlet
Total Flow lb/hr	639,403	447,246	192,156
Enthalpy Btu/hr	-1.4E+09	-9.6E+08	5.92E+07
Overall Mass Difference (lb/hr)			1
Overall Energy Difference (BTU/hr)			-4.86E+08

Stream Report

Table 5: Stream Report for S-101 to S-107

	S-101	S-102	S-103	S-104	S-105	S-106	S-107
Mass Flow lb/hr							
BENZENE	0	14392	4797	4797	4797	4797	4797
TOLUENE	0	230	77	77	77	77	77
P-XYLENE	0	0.24	0.08	0.08	0.08	0.08	0.08
M-XYLENE	0	0.21	0.07	0.07	0.07	0.07	0.07
O-XYLENE	0	0.16	0.05	0.05	0.05	0.05	0.05
METHANOL	0	0	0	0	0	0	0
WATER	0	0	0	0	0	0	0
METHANE	5.64E+05	2.06E+06	6.86E+05	6.86E+05	6.86E+05	6.86E+05	6.86E+05
N2	1.04E+04	51820	17273	17273	17273	17273	17273
H2	0	40461	13487	13487	13487	13487	13487
CO	0	3346	1115	1115	1115	1115	1115
CO2	6.51E+04	2.59E+05	8.65E+04	8.65E+04	8.65E+04	8.65E+04	8.65E+04
NAPHTH	0	1.67	0.56	0.56	0.56	0.56	0.56
O2	0	0	0	0	0	0	0
AIR	0	0	0	0	0	0	0
Total Flow lb/hr	6.39E+05	2.43E+06	8.09E+05	8.09E+05	8.09E+05	8.09E+05	8.09E+05
Temperature F	60	-12	-12	160	-12	160	-12
Pressure psia	200	28	28	91	28	91	28
Vapor Frac	1	1	1	1	1	1	1
Enthalpy Btu/hr	-1.39E+09	-5.22E+09	-1.74E+09	-1.67E+09	-1.74E+09	-1.67E+09	-1.74E+09

Table 6: Stream Report for S-108 to S-114

	S-108	S-109	S-110	S-111	S-112	S-113	S-114
Mass Flow lb/hr							
BENZENE	4797	14392	14392	14392	151653	151653	50550
TOLUENE	77	230	230	230	8256	8256	2752
P-XYLENE	7.89E-02	2.37E-01	2.37E-01	2.37E-01	6.34E+01	6.34E+01	2.11E+01
M-XYLENE	7.16E-02	2.15E-01	2.15E-01	2.15E-01	6.34E+01	6.34E+01	2.11E+01
O-XYLENE	5.35E-02	1.60E-01	1.60E-01	1.60E-01	6.34E+01	6.34E+01	2.11E+01
METHANOL	0	0	0	0	0	0	0
WATER	0	0	0	0	0	0	0
METHANE	6.86E+05	2.06E+06	2.06E+06	2.06E+06	1.87E+06	1.87E+06	6.23E+05
N2	17273	51820	51820	51820	51820	51820	17273
H2	13487	40461	40461	40461	50577	50577	16859
CO	1115	3346	3346	3346	4183	4183	1394
CO2	86465	2.59E+05	2.59E+05	2.59E+05	2.43E+05	2.43E+05	81060
NAPHTH	0.56	1.67	1.67	1.67	49768	49768	16589
O2	0	0	0	0	0	0	0
AIR	0	0	0	0	0	0	0
Total Flow lb/hr	8.09E+05	2.43E+06	2.43E+06	2.43E+06	2.43E+06	2.43E+06	8.09E+05
Temperature F	160	160	1172	1440	1239	250	250
Pressure psia	91	91	75	59	43	27	27
Vapor Frac	1	1	1	1	1	1	1
Enthalpy Btu/hr	-1.67E+09	-5.00E+09	-3.10E+09	-2.44E+09	-2.44E+09	-4.34E+09	-1.45E+09

Table 7: Stream Report for S-115 to S-121

	S-115	**S-116**	**S-117**	**S-118**	**S-119**	**S-120**	**S-121**
Mass Flow lb/hr							
BENZENE	50550	50551	50551	50551	50551	151653	151653
TOLUENE	2752	2752	2752	2752	2752	8256	8256
P-XYLENE	21	21	21	21	21	63	63
M-XYLENE	21	21	21	21	21	63	63
O-XYLENE	21	21	21	21	21	63	63
METHANOL	0	0	0	0	0	0	0
WATER	0	0	0	0	0	0	0
METHANE	6.23E+05	6.23E+05	6.23E+05	6.23E+05	6.23E+05	1.87E+06	1.87E+06
N2	17273	17273	17273	17274	17274	51820	51820
H2	16859	16859	16859	16859	16859	50577	50577
CO	1394	1394	1394	1394	1394	4183	4183
CO2	81060	81061	81061	81061	81061	243182	243182
NAPHTH	16589	16589	16589	16590	16590	49768	49768
O2	0	0	0	0	0	0	0
AIR	0	0	0	0	0	0	0
Total Flow lb/hr	8.09E+05	8.09E+05	8.09E+05	8.09E+05	8.09E+05	2.43E+06	2.43E+06
Temperature F	471	250	471	250	473	472	463
Pressure psia	90	27	90	27	91	90	74
Vapor Frac	1	1	1	1	1	1	1
Enthalpy Btu/hr	-1.33E+09	-1.45E+09	-1.33E+09	-1.45E+09	-1.33E+09	-4.00E+09	-4.02E+09

Table 8: Stream Report for S-122 to S-127

	S-122	S-123	S-124	S-125	S-126	S-127
Mass Flow lb/hr						
BENZENE	151653	151653	133662	17991	14392	3598
TOLUENE	8256	8256	7969	287	230	57
P-XYLENE	63	63	63	0	0	0
M-XYLENE	63	63	63	0	0	0
O-XYLENE	63	63	63	0	0	0
METHANOL	0	0	0	0	0	0
WATER	0	0	0	0	0	0
METHANE	1.87E+06	1.87E+06	2.14E+02	1.87E+06	1.49E+06	3.74E+05
N2	51820	51820	1	51819	41455	10364
H2	50577	50577	0	50577	40461	10115
CO	4183	4183	0	4183	3346	837
CO2	2.43E+05	2.43E+05	354	2.43E+05	1.94E+05	4.86E+04
NAPHTH	49768	49768	49766	2	2	0
O2	0	0	0	0	0	0
AIR	0	0	0	0	0	0
Total Flow lb/hr	2.43E+06	2.43E+06	1.92E+05	2.24E+06	1.79E+06	4.47E+05
Temperature F	110	-30	-32	-32	-32	-32
Pressure psia	59	44	28	28	28	28
Vapor Frac	1	1	0	1	1	1
Enthalpy Btu/hr	-4.55E+09	-4.75E+09	4.39E+07	-4.80E+09	-3.84E+09	-9.59E+08

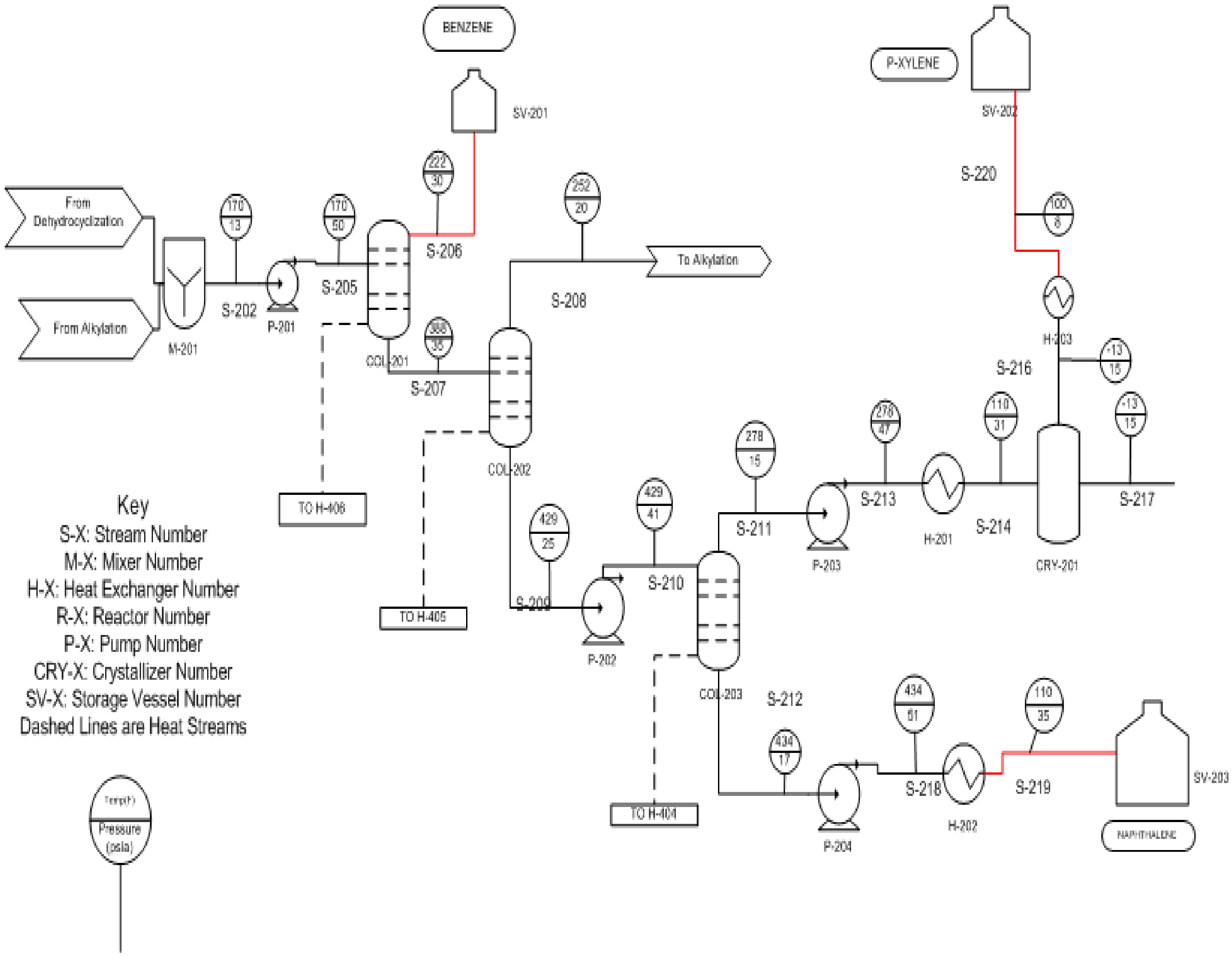

Figure 7: Process for Diagram for Separation Train

Overall Mass & Energy Balance

Table 9: Overall Mass and Energy Balance for Separation Train

	S-201	S-309	S-206	S-208	S-217	S-219	S-220	S-203 (not modeled)
Stream Type	Inlet	Inlet	Outlet	Outlet	Outlet	Outlet	Outlet	Outlet
Total Flow lb/hr	192,156	12,635	137,508	11,702	971	49,892	4149	569
Enthalpy Btu/hr	5.92E+07	-5.91E+05	4.38E+07	1.56E+06	-8.78E+04	1.66E+07	-3.80E+05	-1.77E+06
Overall Mass Difference (lb/hr)	0							
Overall Energy Difference (BTU/hr)	-1.16E+06							

Stream Report:

Table 10: Stream Report for S-201 to S-207

	S-201	**S-202**	**S-203**	**S-204**	**S-205**	**S-206**	**S-207**
Mass Flow lb/hr							
BENZENE	1.34E+05	1.34E+05	0	1.34E+05	1.34E+05	1.34E+05	0
TOLUENE	7969	15482	0	1.55E+04	1.55E+04	3516	1.20E+04
P-XYLENE	63	4855	0	4855	4855	0	4855
M-XYLENE	63	63	0	63	63	0	63
O-XYLENE	63	63	0	63	63	0	63
METHANOL	0	301	0	301	301	301	0
WATER	0	29	0	29	29	29	0
METHANE	214	214	214	0	0	0	0
N2	1	1	1	0	0	0	0
H2	0.29	0.29	0.29	0	0	0	0
CO	0.11	0.11	0.11	0	0	0	0
CO2	354	354	354	0	0	0	0
NAPHTH	49766	49766	0	49766	49766	0	49766
O2	0	0	0	0	0	0	0
AIR	0	0	0	0	0	0	0
Total Flow lb/hr	1.92E+05	2.05E+05	569	2.04E+05	2.04E+05	1.38E+05	6.67E+04
Temperature F	170	171	171	171	171	222	388
Pressure psia	13	13	13	13	50	30	35
Vapor Frac	0.05	0.04	1	0	0	0	0
Enthalpy Btu/hr	5.92E+07	5.86E+07	-1.77E+06	5.93E+07	5.93E+07	4.38E+07	2.51E+07

Table 11: Stream Report for S-208 to S-214

	S-208	S-209	S-210	S-211	S-212	S-213	S-214
Mass Flow lb/hr							
BENZENE	0	0	0	0	0	0	0
TOLUENE	11702	264	264	264	0	264	264
P-XYLENE	0	4855	4855	4732	123	4732	4732
M-XYLENE	0	63	63	61	2	61	61
O-XYLENE	0	63	63	59	4	59	59
METHANOL	0	0	0	0	0	0	0
WATER	0	0	0	0	0	0	0
METHANE	0	0	0	0	0	0	0
N2	0	0	0	0	0	0	0
H2	0	0	0	0	0	0	0
CO	0	0	0	0	0	0	0
CO2	0	0	0	0	0	0	0
NAPHTH	0	49766	49766	3	49763	3	3
O2	0	0	0	0	0	0	0
AIR	0	0	0	0	0	0	0
Total Flow lb/hr	11702	55012	55012	5120	49892	5120	5120
Temperature F	252	429	429	278	434	278	110
Pressure psia	20	25	41	15	17	47	31
Vapor Frac	0	0	0	0	0	0	0
Enthalpy Btu/hr	1.56E+06	2.39E+07	2.39E+07	-9671.08	2.36E+07	-7488.18	-4.05E+05

Table 12: Stream Report for S-215 to S-220

	S-215	S-216	S-217	S-218	S-219	S-220
Mass Flow lb/hr						
BENZENE	0	0	0	0	0	0
TOLUENE	264	0	264	0	0	0
P-XYLENE	4732	4141	592	123	123	4141
M-XYLENE	61	0	61	2	2	0
O-XYLENE	59	8	51	4	4	8
METHANOL	0	0	0	0	0	0
WATER	0	0	0	0	0	0
METHANE	0	0	0	0	0	0
N2	0	0	0	0	0	0
H2	0	0	0	0	0	0
CO	0	0	0	0	0	0
CO2	0	0	0	0	0	0
NAPHTH	3	0	3	49763	49763	0
O2	0	0	0	0	0	0
AIR	0	0	0	0	0	0
Total Flow lb/hr	5120	4149	971	49892	49892	4149
Temperature F	-13	-13	-13	434	110	100
Pressure psia	15	15	15	51	35	8
Vapor Frac	0	0	0	0	0	0
Enthalpy Btu/hr	-6.46E+05	-5.58E+05	-87841.8	2.36E+07	1.66E+07	-3.80E+05

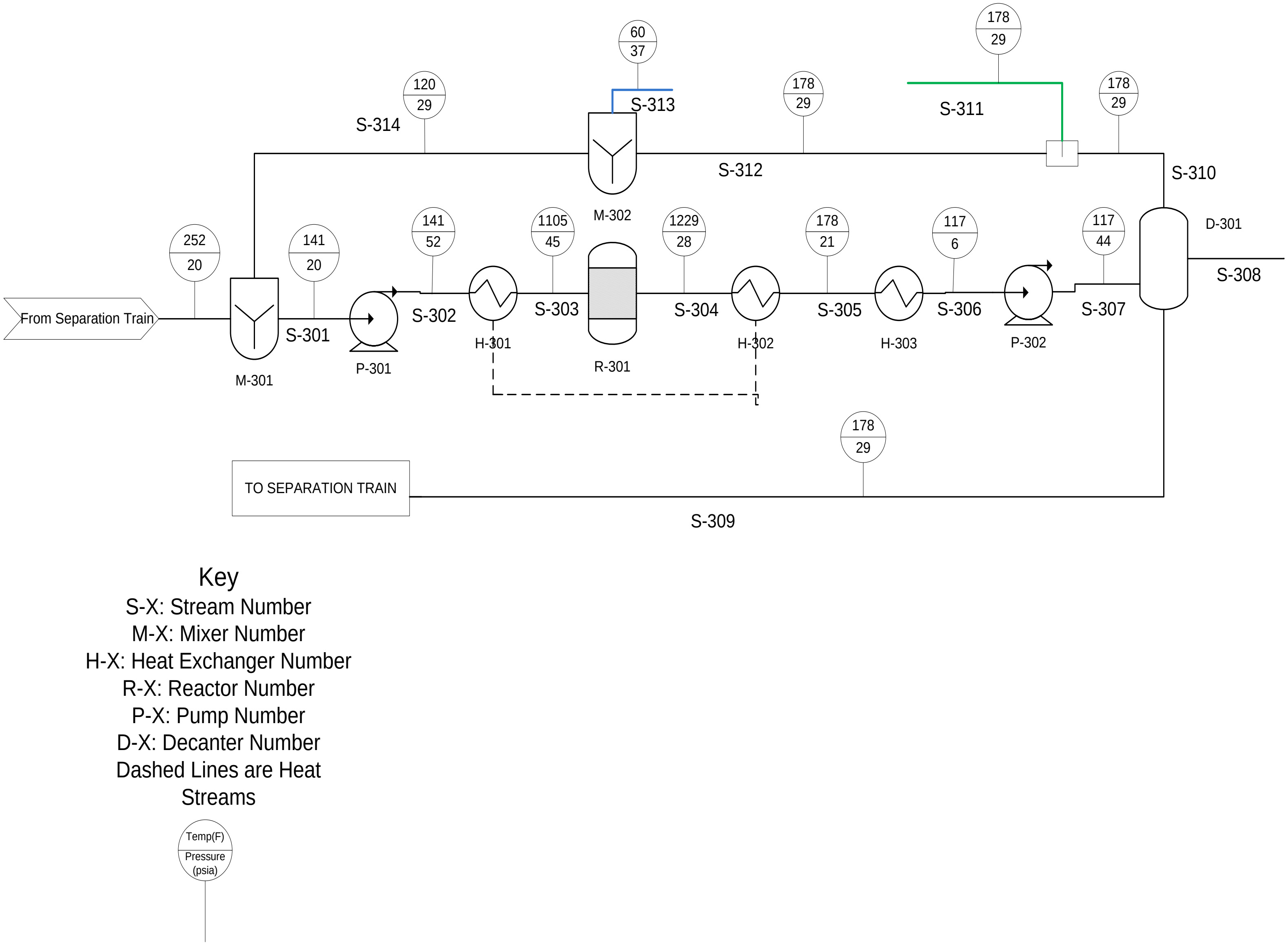

Figure 8: Process Flow Diagram for Alkylation

Overall Mass & Energy Balance:

Table 13: Overall Mass & Energy Balance for Alkylation

	S-208	S-309	S-311	S-313
Stream Type	Inlet	Outlet	Outlet	Inlet
Total Flow lb/hr	11,702	12,635	1310	2243
Enthalpy Btu/hr	-2.03E+07	-5.91E+05	-6.82E+06	-7.34E+06
Overall Mass Difference (lb/hr)			0.02	
Overall Energy Difference (BTU/hr)			-2.02E+07	

Stream Report:

Table 14: Stream Report for S-301 to S-307

	S-301	S-302	S-303	S-304	S-305	S-306	S-307
Mass Flow lb/hr							
BENZENE	0	0	0	0	0	0	0
TOLUENE	11758	11758	11758	7596	7596	7596	7596
P-XYLENE	9	9	9	4805	4805	4805	4805
M-XYLENE	0	0	0	0	0	0	0
O-XYLENE	0	0	0	0	0	0	0
METHANOL	3295	3295	3295	1847	1847	1847	1847
WATER	1667	1667	1667	2481	2481	2481	2481
METHANE	0	0	0	0	0	0	0
N2	0	0	0	0	0	0	0
H2	0	0	0	0	0	0	0
CO	0	0	0	0	0	0	0
CO2	0	0	0	0	0	0	0
NAPHTH	0	0	0	0	0	0	0
O2	0	0	0	0	0	0	0
AIR	0	0	0	0	0	0	0
Total Flow lb/hr	16729	16729	16729	16729	16729	16729	16729
Temperature F	142	142	1105	1231	178	117	117
Pressure psia	20	52	45	28	21	6	44
Vapor Frac	0	0	1	1	0	0	0
Enthalpy Btu/hr	-2.03E+07	-2.03E+07	-7.46E+06	-7.46E+06	-2.03E+07	-2.19E+07	-2.19E+07

Table 15: Stream Report for S-308 to S-314

	S-308	S-309	S-310	S-311	S-312	S-313	S-314
Mass Flow lb/hr							
BENZENE	0	0	0	0	0	0	0
TOLUENE	0	7513	83	27	56	0	56
P-XYLENE	0	4792	13	4	9	0	9
M-XYLENE	0	0	0	0	0	0	0
O-XYLENE	0	0	0	0	0	0	0
METHANOL	0	301	1547	495	1052	2243	3295
WATER	0	29	2452	785	1667	0	1667
METHANE	0	0	0	0	0	0	0
N2	0	0	0	0	0	0	0
H2	0	0	0	0	0	0	0
CO	0	0	0	0	0	0	0
CO2	0	0	0	0	0	0	0
NAPHTH	0	0	0	0	0	0	0
O2	0	0	0	0	0	0	0
AIR	0	0	0	0	0	0	0
Total Flow lb/hr	0	12635	4094	1310	2784	2243	5027
Temperature F		181	181	178	178	60	120
Pressure psia	29	29	29	29	29	37	29
Vapor Frac		0	0	0	0	0	0
Enthalpy Btu/hr		-5.91E+05	-2.13E+07	-6.82E+06	-1.45E+07	-7.34E+06	-2.18E+07

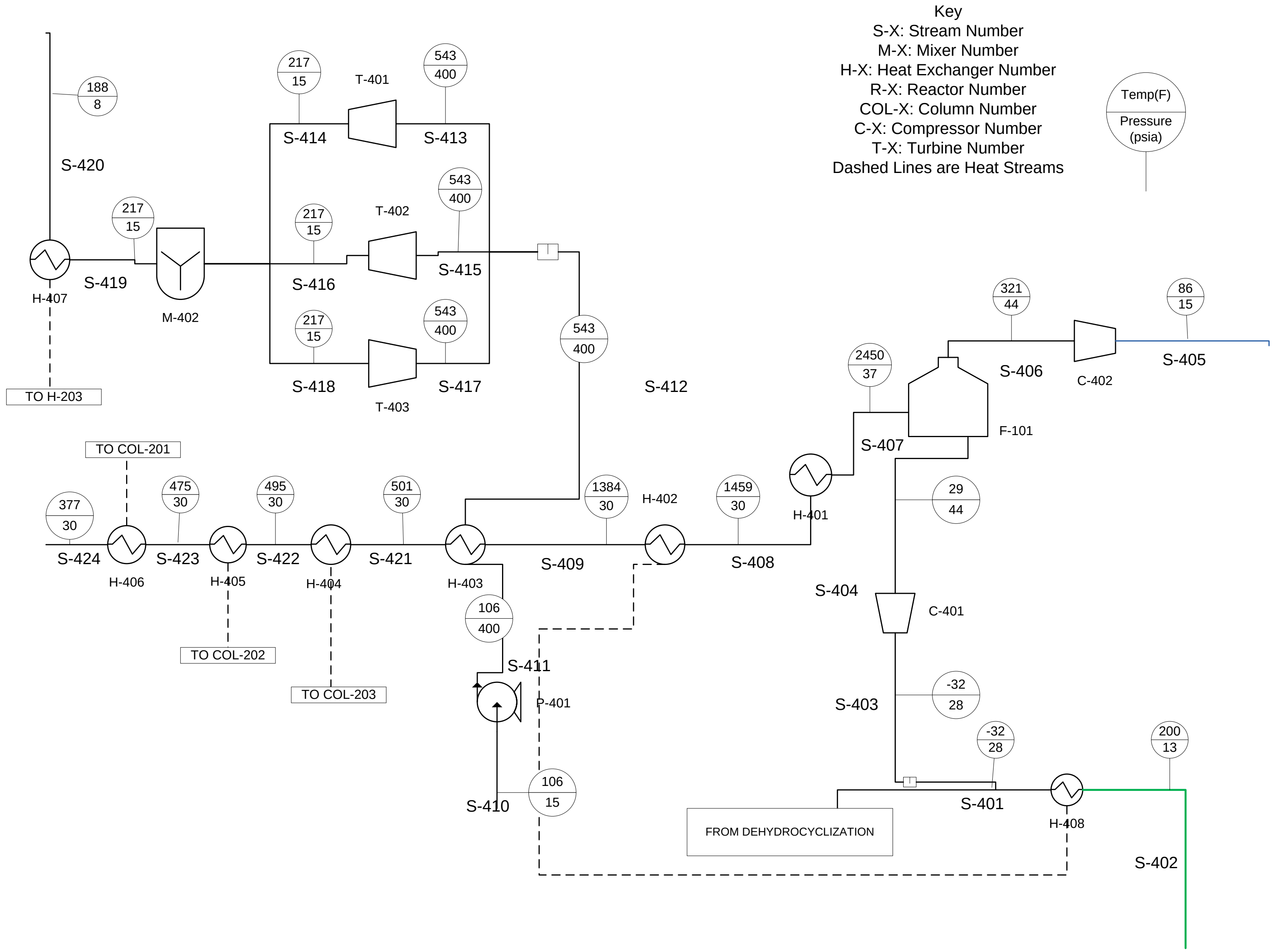

Figure 9: Process Flow Diagram for Furnace Section

Overall Mass & Energy Balance:

Table 16: Overall Mass & Energy Balance for Furnace Section

	S-127	S-402	S-405	S-410	S-420	S-424
Stream Type	Inlet	Outlet	Inlet	Inlet	Outlet	Outlet
Total Flow lb/hr	447,246	368,978	2,019,530	414,351	414,351	2,097,800
Enthalpy Btu/hr	-9.59E+08	-7.44E+08	4.20E+06	-2.84E+09	-2.41E+09	-1.35E+09
Overall Mass Difference (lb/hr)						-2
Overall Energy Difference (BTU/hr)						7.02E+08

Stream Report:

Table 17: Stream Report for S-401 to S-406

	S-401	S-402	S-403	S-404	S-405	S-406
Mass Flow lb/hr						
BENZENE	2.97E+03	2.97E+03	6.30E+02	629.669	0	0
TOLUENE	47	47	10	10	0	0
P-XYLENE	0	0	0	0	0.00E+00	0.00E+00
M-XYLENE	0.04	0.04	0	0	0	0
O-XYLENE	0.03	0.03	0	0	0	0
METHANOL	0	0	0	0	0	0
WATER	0	0	0	0	0	0
METHANE	3.08E+05	3.08E+05	65399	65399	0	0
N2	8550	8550	1814	1814	1.55E+06	1.55E+06
H2	8345	8345	1770	1770	0	0
CO	690	690	146	146	0	0
CO2	40067	40067	8499	8499	0	0
NAPHTH	0.35	0.35	0.07	0.07	0	0
O2	0	0	0	0	4.70E+05	4.70E+05
AIR	0	0	0	0	0	0
Total Flow lb/hr	3.69E+05	3.69E+05	78268	78268	2.02E+06	2.02E+06
Temperature F	-32	200	-32	29	86	321
Pressure psia	28	13	28	44	15	44
Vapor Frac	1	1	1	1	1	1
Enthalpy Btu/hr	-7.92E+08	-7.44E+08	-1.68E+08	-1.65E+08	4.20E+06	1.19E+08

Table 18: Stream Report for S-407 to S-412

	S-407	**S-408**	**S-409**	**S-410**	**S-411**	**S-412**
Mass Flow lb/hr						
BENZENE	630	630	630	0	0	0
TOLUENE	10	10	10	0	0	0
P-XYLENE	0	0.01	0.01	0	0	0
M-XYLENE	0	0	0	0	0	0
O-XYLENE	0	0	0	0	0	0
METHANOL	0	0	0	0	0	0
WATER	1.46E+05	1.46E+05	1.46E+05	4.14E+05	4.14E+05	4.14E+05
METHANE	6540	6540	6540	0	0	0
N2	1.55E+06	1.55E+06	1.55E+06	0	0	0
H2	177	177	177	0	0	0
CO	146	146	146	0	0	0
CO2	1.70E+05	1.70E+05	1.70E+05	0	0	0
NAPHTH	0.07	0.07	0.07	0	0	0
O2	2.23E+05	2.23E+05	2.23E+05	0	0	0
AIR	0	0	0	0	0	0
Total Flow lb/hr	2.10E+06	2.10E+06	2.10E+06	4.14E+05	4.14E+05	4.14E+05
Temperature F	2450	1459	1384	106	106	543
Pressure psia	37	30	30	15	400	400
Vapor Frac	1	1	1	0	0	1
Enthalpy Btu/hr	-4.61E+07	-7.03E+08	-7.51E+08	-2.84E+09	-2.84E+09	-2.31E+09

Table 19: Stream Report for S-412 to S-418

	S-413	**S-414**	**S-415**	**S-416**	**S-417**	**S-418**
Mass Flow lb/hr						
BENZENE	0	0	0	0	0	0
TOLUENE	0	0	0	0	0	0
P-XYLENE	0	0	0	0	0	0
M-XYLENE	0	0	0	0	0	0
O-XYLENE	0	0	0	0	0	0
METHANOL	0	0	0	0	0	0
WATER	1.38E+05	1.38E+05	1.38E+05	1.38E+05	1.38E+05	1.38E+05
METHANE	0	0	0	0	0	0
N2	0	0	0	0	0	0
H2	0	0	0	0	0	0
CO	0	0	0	0	0	0
CO2	0	0	0	0	0	0
NAPHTH	0	0	0	0	0	0
O2	0	0	0	0	0	0
AIR	0	0	0	0	0	0
Total Flow lb/hr	1.38E+05	1.38E+05	1.38E+05	1.38E+05	1.38E+05	1.38E+05
Temperature F	543	217	543	217	543	217
Pressure psia	400	15	400	15	400	15
Vapor Frac	1	0.90	1	0.90	1	0.90
Enthalpy Btu/hr	-7.71E+08	-8.02E+08	-7.71E+08	-8.02E+08	-7.71E+08	-8.02E+08

Table 20: Stream Report for S-419 to S-424

	S-419	**S-420**	**S-421**	**S-422**	**S-423**	**S-424**
Mass Flow lb/hr						
BENZENE	0	0	630	630	630	630
TOLUENE	0	0	10	10	10	10
P-XYLENE	0	0	0.01	0.01	0.01	0.01
M-XYLENE	0	0	0	0	0	0
O-XYLENE	0	0	0	0	0	0
METHANOL	0	0	0	0	0	0
WATER	4.14E+05	4.14E+05	1.46E+05	1.46E+05	1.46E+05	1.46E+05
METHANE	0	0	6540	6540	6540	6540
N2	0	0	1.55E+06	1.55E+06	1.55E+06	1.55E+06
H2	0	0	177	177	177	177
CO	0	0	146	146	146	146
CO2	0	0	1.70E+05	1.70E+05	1.70E+05	1.70E+05
NAPHTH	0	0	0.07	0.07	0.07	0.07
O2	0	0	2.23E+05	2.23E+05	2.23E+05	2.23E+05
AIR	0	0	0	0	0	0
Total Flow lb/hr	4.14E+05	4.14E+05	2.10E+06	2.10E+06	2.10E+06	2.10E+06
Temperature F	217	188	501	495	475	377
Pressure psia	15	8	30	30	30	30
Vapor Frac	0.90	0.92	1	1	1	1
Enthalpy Btu/hr	-2.41E+09	-2.41E+09	-1.28E+09	-1.28E+09	-1.29E+09	-1.35E+09

Process Description

The overall process was split into four sections: dehydrocyclization for BTX production (Section I), separation of aromatics (Section II), alkylation of toluene into p-xylene (Section III), and a furnace for heat and steam generation (Section IV).

Dehydrocyclization

The dehydrocyclization process converts the natural gas feed, which is primarily composed of methane, to the aromatics benzene, toluene, xylene, and naphthalene. The reactions for dehydrocyclization are based off the patent application US 20,100,099,935 and are described in previous sections of this report. Using these reactions as well as the laboratory testing provided by the catalyst patent given in the project charter (US 8,278,237), an adiabatic, fixed bed reactor with a zeolite catalyst was designed. The reactor was run adiabatically in order to determine the maximum temperature change that would occur, as the effluent to the reactor was used to heat the feed. The natural gas feed and the recycled methane feed were heated to the reaction temperature of 1440 F and compressed to achieve 43 psia at the reactor outlet (after a 15 psia drop for each unit encountered). Three carbon-steel reactors are required for the plant: one running, one on standby, and one regenerating catalyst. Each reactor has a ceramic lining to accommodate the high temperature of reaction. An overall 12.4% methane conversion is reached by the reactor. The amount of natural gas feed and catalyst required was determined by the BTX formation rate and the required production of 1 B BTX/yr. The vapor effluents of the reactor first used to head the reactor feed and then cooled to ambient temperature. The stream is then refrigerated by a propane refrigeration system to -31 F and sent to an adiabatic flash distillation column. The light products from this column are purged and recycled back into the reactor feed to convert as much methane as possible. The purge stream from this section is heated and sold for its heating value. The purge stream previously mentioned made up 20% of the overhead products from the flash distillation. This purge is a crucial step in eliminating the hydrogen from recycling back into the reactor feed. This purge was used to heat reactor inlet streams, and to provide heat for the reboilers involved in the aromatic separation. The bottoms products from this column (COL-101) are sent to the separation train.

Furnace

Section IV, referred to as "the Furnace Section," serves to generate the heat required for our process streams. Since the low conversion of the catalyst used in Section I requires us to purge a significant amount of our unreacted methane, we designed a section to recover this otherwise-wasted energy. The most important function of the furnace section is to heat the feed to the dehydrocyclization reactor to its required temperature of 1440 F, thus the entire section was designed around this purpose. The furnace must reach a temperature of at least 1500 F, so enough CH_4 and H_2 must be combusted to achieve this temperature. Furthermore, the furnace must also generate enough heat to supply the reboilers in COL-201, COL-202, and COL-203. Because of these facts, only 17.5% of the purge stream S-127 is sent to the furnace to be combusted. The remaining contents are sold at heating value ($4/MMBTU).

The furnace itself is modeled as a direct fire heater and produces over 160MM BTU/hr. This unit will be at the front of a long box containing three different sets of coiled tubing. After the CH_4 and H_2 are combusted in the furnace, the flue gas will pass over these sets of coil tubing and heat the process streams inside them. In the first set of coil tubing, H-401, heat will be absorbed by the dehydrocyclization feed stream (S-110) since this stream has the hottest temperature requirement. The next set of coil tubing, modeled as H-402, serves to heat S-401 to ambient conditions. The final set of coil tubing, H-403, serves as the steam generator for our turbine generators. After passing over the three sets of coil tubing, the furnace flue gas will be at a temperature of approximately 500 F. The remaining heat in the flue gas will be used to heat the reboilers in COL-201, COL-202, and COL-203. After these exchanges, the flue gas will be sent to the flare and exit the process.

The furnace is fed using the purge stream from Section I and air at 150% excess. This amount of excess serves to keep the mixture within its flammability limits, as well as to keep the furnace from reaching excessive temperatures. By using so much excess air supply, the furnace temperature is kept to 2450 F. A drawback to a high excess air ratio, however, is that we must use a larger compressor to overcome the pressure drops in downstream exchangers. This cost, however, is necessary to operate our furnace.

The turbine generators mentioned previously serve to capture the energy available in the furnace effluent. After H-402, the flue gas is too hot to be used elsewhere in the process, so it must be cooled. In order to not simply lose the energy available in the stream, steam generation can be used. The energy available after H-402 in the flue gas is enough to generate 530MM BTU/hr of steam at a pressure of 400 psia and 100 F of superheat. This stream is run through three 12,000 hp turbines to generate 27 MW. While this power output does not make up for the power used in the compressors feeding the furnace, the available energy is recovered rather than lost as it would be without steam generation. The 52,000 gal/hr of water used for steam generation will come from the water that has already been used as cooling water elsewhere in the system and will not require the purchase of additional water. After generating power in the turbines, the exit steam is used to heat the paraxylene product stream exiting the crystallizer (S-216) so that it can be transported and stored as a liquid.

Separation Train

The bottoms products from the flash distillation column as well as the recycle stream from the alkylation process are sent through an aromatic separation train. The end goal of this section is to produce pure benzene, paraxylene, and naphthalene products. A final effluent from this process is a toluene-rich stream that is sent to an alkylation unit for paraxylene production. Separation is entirely done by multi-staged distillation columns, and a crystallizer to increase the purity of the paraxylene product stream. Heat to vaporize the boilup in each distillation column was provided by the heat generated by the furnace.

Separation occurs by direct sequencing. The first column, COL-201, produces a 97.2% pure benzene product that is sent to storage. Heat for the reboiler of the column was provided by H-406. Because the production of benzene product is so rapid (approximately 21,000 gallons per hour), two large storage barges are onsite to store product for a 6 day maximum holdup period. These storage vessels are designed to hold 1.5MM gallons. The second column, COL-202, produces 99.9% pure toluene stream that is sent to the alkylation process. Heat for the reboiler of the column was provided by H-405. Finally, the third column, COL-203, produces a bottoms product of 99.7% pure naphthalene and an overhead product is rich in paraxylene. Heat for the reboiler of the column was provided by H-404.This stream is 91.7% pure and is sent to CRY-201 for further purification. Customers require 99.8% purity for paraxylene. The crystallizer is designed after US 20,100,137,660 patent application. The mother liquor from this crystallization is rich in toluene, m-xylene, and o-xylene. The p-xylene product has a 99.8 mol% purity, with the impurities made up by o-xylene. This product is then liquefied using heat provided by H-407, and subsequently sent to a storage vessel. 1.5 MM gallon storage tanks are used to hold the paraxylene and naphthalene products as well. Maximum holdup times for paraxylene and naphthalene are 100 days and 10 days, respectively.

Alkylation

Toluene from the aromatics separation was pumped and heated to 1140 F and 45 psia to meet the alkylation reactor specifications. The alkylation reaction was also fed a stream of fresh methanol, to be used as an alkylating agent. The following reaction was used:

1. $CH_3OH + C_7H_8 \rightarrow C_8H_{10} + H_2O$

The reactor is an adiabatic, fluidized bed that generates paraxylene with the aid of a zeolite catalyst. The reactor has a 35% conversion of toluene. 2243 lb/hr of fresh methanol feed is fed into the reactor. Effluent from the reactor is cooled and pumped into a decanter. The decanter uses the immiscibility between water, methanol, and the aromatic products undergo separation. The decanter is adiabatic and operates at 29 psia. 32% of the liquid water-methanol outlet stream is purged in order to remove the excess water. The remaining water-methanol mixture is sent back to the reactor. The aromatic outlet stream, which is primarily composed of 59% unreacted toluene and 33% paraxylene, is sent back to the separation train through a recycle stream.

UTILITY REQUIREMENTS

Utility Requirements

To keep the process as efficient as possible, heat exchangers for this process were designed to be highly integrated, meaning that every stream was evaluated for its potential to heat or cool another process stream. This would eliminate any unnecessary utility purchases when warranted. We have enough heat available in our system such that no heating utilities are required to be purchased, due to the high heat of combustion of H_2 and CH_4. Between the reactor effluents and methane-rich purge stream, enough heat is available to heat all streams that require heating. Our process only requires utilities for lowering the temperature of process streams and powering pumps and compressors. In addition to providing the duty required to heat any process streams, there is still heat left over to generate high pressure steam to power three large turbines, as well as a large amount that can be sold at its fuel value. All heat exchangers involving cooling water were designed to allow the cooling water to rise from 86 °F to 106 °F, as is common in the Gulf of Mexico. The lowest value a process stream was cooled to using cooling water was 110 F as to maintain a ΔT_{min} of 24 °F across the heat exchanger to affect heat transfer. In total, the process uses no outside energy for heating, 3.3MM gal/hr of cooling water (24 gal/lb of product), and 244 MW of electricity (1.78 kW per pound of product per hour).

H-101 and H-103, while diagramed as separate heat exchangers, will in practice be one heat exchanger that will use two process streams during its operation. The hot stream will be the effluent of the dehydrocyclization reactor, which exits the reactor at above 1200 F, and the cold stream will be the natural gas feed and recycle stream. H-101 and H-103 will take all available duty from the reactor effluent and use it to heat the feed to the reactor. The results of this exchange is that the reactor effluent is cooled to 250 F, and the feed to the reactor is heated to approximately 1170 F. The effluent is not cooled further since the unit immediately following this reactor is a compressor, and cooling the effluent below 250 F would cause the fluid to drop below its dew point. Due to the dehydrocyclization reaction being endothermic, the temperature available in the reactor effluent is only able to heat the reactor feed to 1170 F after cross heating, which is not hot enough for the required 1440 F temperature specification set aside by the catalyst patent given in the problem statement (US ‘237). To accomplish this final stage of heating, another heat exchanger is added before the reactor that uses the heat from burning the methane-rich purge stream, as described in the paragraphs below. H-102 and H-108 work similarly to H-101 and H-103, where H-108 sends the required duty as calculated by H-102 to the feed stream. In reality, H-102 and H-108 will be one exchanger, and will be a system of coils running through the furnace (F-401) that is burning a fraction of the purge stream. This way, the feed to the reactor is successfully heated to the required temperature.

H-104 and H-107 work in the same way that the two above pairs of heat exchangers do. H-104 will use the available duty in the bottoms product of COL-101 to cool itself before being fed to the flash. As with H-101, the duty available is not enough to cool the stream to ambient conditions, so H-105 is added immediately afterwards to cool the stream. H-105 uses cooling water to cool the stream and accomplishes an exit temperature of 110 F for the process stream. Since COL-101 requires being cooled to close to -30 F, more extensive cooling is yet required on the reactor effluent. Clearly, this temperature cannot be reached with liquid water, so a propane cooling unit is used to accomplish this temperature. To accomplish optimal separation, we specified the vapor fraction of COL-101 to be approximately equal to the total amount of non-aromatic components that entered the vessel. At adiabatic conditions, this vessel operates at -31

F and is cooled using a propane refrigeration unit. The unit is treated as a one-time capital expense, and accomplishes an exchange of 206 MM BTU/hr.

As a means of fully integrating heat exchange in our process, we designed a furnace that burns a fraction of the purge stream containing 78 mol% CH_4. Since material in this stream would have been lost anyway, burning the purge allows us to minimize our utility requirements by capturing a portion of the large amount of energy available in methane-rich this stream. The stream fed to the furnace is only a fraction of the purge since the temperature resulting from burning the entirety of the purge was too high to be used. Stream S-125, the vapor stream from the flash vessel COL-101, is split such that 3.5% of the CH_4 that exits the flash as a vapor is compressed and fed to the furnace to be burned. The furnace was modeled as an adiabatic direct-fire heater so that the outlet temperatures of the process streams can be known. The reactions modeled in the furnace are as such:

1. $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$
2. $2H_2 + O_2 \rightarrow 2H_2O$

Reactions involving aromatics were not included in the furnace model since they make up about 0.2 mol% of the vapor product of COL-101. The furnace is fed with air in excess so to maintain a high conversion of CH_4 and H_2. The degree of excess of the air feed was initially designed to be small as to minimize the size of compressors that increase the pressure of feeds to the furnace. However, the temperature of the furnace at low excess air was far too high to be used elsewhere in the process, so the excess air was increased until feasible temperatures were attained. The final value of excess air that is fed to the furnace is 150%. This did in turn greatly increase the required size of the compressors as the flow rate of air increased, but the excess air was necessary in order to yield useful temperatures in the furnace. While it may make sense to compress the methane-rich stream and the air feed in the same unit, this is an intrinsically unsafe design. By compressing them separately, the air and methane streams will not mix until they are in the furnace, which avoids having a combustible mixture at high pressures.

As previously mentioned, H-401 will exist as part of the furnace as an arrangement of coils, but its purpose is to heat the feed to the dehydrocyclization reactor to the required temperature of 1440 F. The next hottest location that requires heating is the reboiler of COL-203, which has an operating temperature of 432 F. Since the furnace effluent is still too hot after heating the reactor feed, the stream must be cooled to 500 F before it can be used in the reboiler, which means decreasing the temperature by around 1000 F. Since this of course cannot be done in a standard heat exchanger, we elected to use the heat available to generate steam for the purposes of power generation in turbines. This will cut down on the enormous amount of power we require for our process and achieve the desired decrease in temperature. By integrating power generation through steam, we are able to reduce our power requirement for compressors in section IV from 35 MW to 19 MW, a reduction of 45%. Steam is generated in H-403 and the flowrate of the water feed to be converted to steam is determined by the required duty to cool the combusted stream by 1000 F.

Since only a fraction of the purge stream from Section I is fed to the furnace, the remaining fraction of the purge will be sold at its heating value to a nearby consumer (this will likely be another plant or refinery). As such, H-408 serves to bring this stream to ambient conditions so that it may be transmitted to the consumer. H-404, H-405, and H-406 all serve to send heat from the combusted stream to the reboilers of the three columns in Section II, COL-201, COL-202, and COL-203. H-407 serves to liquefy the product of the crystallizer in Section II at the end of the separation train. This is the finals step in purifying paraxylene, after which the pure product stream is sent to a storage tank.

In Section II, the only outside utilities that are required are for the pumps and condensers. All three columns use total condensers in the distillate, so significant duties are required at these locations. The four pumps in Section II require less than 20 kW, so this is not a major sink for energy in the process. H-201 serves to cool the condensed distillate of the final column, which is above 90 mol% paraxylene, with cooling water to ambient conditions. Since crystallization occurs at -13 F, further cooling is required which will occur in the jacket of the crystallizer. H-202 serves to cool the bottoms product of COL-203 to ambient conditions using cooling water. H-203 refers to the exchange of heat taken from H-407, which serves to liquefy the PX crystals after crystallization. Even though H-203 and H-407 are shown as two exchangers, they will be designed and costed as a single unit as seen with other pairs of exchangers.

In the alkylation section of the process, Section III, the utilities are relatively minimal, since this section of the process sees the smallest flow rates. There are three numbered heat exchangers, H-301, H-302, and H-303, of which H-301 and H-302 are in reality the same exchanger. H-301 and H-302 are designed to heat the feed to the reactor by using the effluent stream. Since the alkylation reaction is exothermic, there is enough heat available in the exit to heat the feed without any outside heat source. H-303 serves to cool the reactor effluent further to just above ambient conditions in order to completely condense any remaining vapor exiting the reactor to be fed to the decanter which is operated such that no vapor phase is generated. P-301 and P-302, the only pumps in Section III, serve to counteract any pressure drops in the other units in Section III, such as heat exchangers and the fluidized bed reactor. These pumps require a total power of less than 2 kW. The methanol and water stream that is not recycled to alkylation must be disposed of due to contamination by BTX products. This will be done on a contractual basis as needed.

Section IV was designed to generate all of the required heating for the process outside of what was available in reactor effluents. This section generates 730 MM BTU/hr of heat for the process and consumes 19 MW (65 MM BTU/hr) of net power. The most power-intensive unit in Section IV is the compressor feeding air to the furnace, C-402, which requires 34 MW. This is partially offset by the steam generation and turbines, which do not generate enough power to operate C-402 but reduce the required outside power we must purchase by 45% for Section IV.

All of the heat exchangers involving cooling water (H-105, H-201, H-202, and H-303) require a total of 3.3MM gallons of water an hour to operate. While this number is high, it is not a product of inefficient heaters or design that leads to a high demand for cooling water. Rather, the scale of our process is such that even a small change in temperature for a large stream requires a large amount duty to accomplish. It is feasible that this flow rate of water may be difficult to maintain in the warm climate of the Gulf of Mexico, but as long as enough storage is maintained in the proximity of the process there should be no issue attaining the required flow rate.

In summary, the excess of heat available in our process was used whenever available in order to minimize the amount of utilities for heating that were required for purchase. While it is not often ideal to purge 20% of a recycle stream, we used this purge stream to provide all of the remaining heating utilities for the process. We require very large rates of cooling water and electricity due to the high flow rates of the process, but our costs have been minimized by the use of heat within the process and the capture of energy through steam generation. The total amount of cooling water required is 3.3MM gal/hr (24 gal/hr per pound of benzene) and the total amount of electricity required at full capacity is 244 MW (1.8 kW per pound of benzene).

Electricity Requirements of the Process				
Equipment	**Description**	**Utility (MW)**	**Source**	
Section I				
C-101	Compressor	21.7	Electricity	
C-102	Compressor	21.7	Electricity	
C-103	Compressor	21.7	Electricity	
C-104	Compressor	33.4	Electricity	
C-105	Compressor	33.4	Electricity	
C-106	Compressor	33.4	Electricity	
H-106	Propane Cooling	60.0	Electricity	
		225.5		*Net Section I*
Section II		**Utility (kW)**		
P-201	Pump	10.8	Electricity	
P-202	Pump	1.6	Electricity	
P-203	Pump	0.6	Electricity	
P-204	Pump	3.1	Electricity	
		16.1		*Net Section II*
Section III				
P-301	Pump	0.83	Electricity	
P-302	Pump	0.96	Electricity	
		1.8		*Net Section III*
Section IV		**Utility (MW)**		
C-401	Compressor	0.7	Electricity	
C-402	Compressor	33.7	Electricity	
T-401	Turbine Generator	-5.2	Steam	
T-402	Turbine Generator	-5.2	Steam	
T-403	Turbine Generator	-5.2	Steam	
		19.0		*Net Section IV*
		MW	kW per lb of Product	
	Total Consumed	**260**	**1.89**	
	Total Generated	**-15**	**-0.11**	
	Net Power Use	**244**	**1.78**	

Heat Requirements of the Process			
Equipment	**Source**	**Utility (BTU/hr)**	
Section I			
H-101	H-103	1.90E+09	
H-102	H-401	6.57E+08	
H-103	H-101	-1.90E+09	
H-104	H-107	-1.53E+07	
H-105	Cooling Water	-5.31E+08	
H-106	Propane Refrigeration	-2.06E+08	
H-107	H-104	1.53E+07	
		-8.01E+07	*Net Section I*
Section II			
H-201	Cooling Water	-3.98E+05	
H-202	Cooling Water	-6.96E+06	
Crystallizer	Freons	-2.40E+05	
H-203	H-407	1.78E+05	
		-7.60E+06	*Net Section II*
Section III			
COL-201 Condenser	Cooling Water	-4.50E+07	
COL-201 Reboiler	H-406	5.46E+07	
COL-202 Condenser	Cooling Water	-1.09E+07	
COL-202 Reboiler	H-405	1.12E+07	
COL-203 Condenser	Cooling Water	-3.64E+06	
COL-203 Reboiler	H-404	3.32E+06	
H-301	H-302	1.28E+07	
H-302	H-301	-1.28E+07	
H-303	Cooling Water	-1.64E+06	
		8.00E+06	*Net Section III*
Section IV			
F-101	Adiabatic Combustion	0.00E+00	
H-401	H-102	-6.57E+08	
H-402	H-408	4.78E+07	
H-403	Water to Steam	0.00E+00	(No net exchange)
H-404	COL-203 Reboiler	-3.32E+06	
H-405	COL-202 Reboiler	-1.12E+07	
H-406	COL-201 Reboiler	-5.46E+07	
H-407	H-203	-1.78E+05	
H-408	H-402	-4.78E+07	
		-7.26E+08	*Net Section IV*
Totals			
Net Exchange		**-806**	MM BTU/hr
Exchange per lb of Product		**-5,861**	BTU/hr

Cooling Water Requirements of the Process		
Equipment	**Duty (BTU/hr)**	**Cooling Water Flow (gal/hr)**
H-105	-5.31E+08	2.89E+06
H-201	-3.98E+05	2.17E+03
H-202	-6.96E+06	3.80E+04
H-303	-1.64E+06	8.91E+03
COL-201 Condenser	-4.50E+07	2.46E+05
COL-202 Condenser	-1.09E+07	5.97E+04
COL-203 Condenser	-3.64E+06	1.99E+04
Total	-6.00E+08	3.27E+06
Total per lb of Product	**-4,361**	**24**

EQUIPMENT LIST, UNIT DESCRIPTIONS, AND SPECIFICATION SHEETS

Unit Descriptions

Columns

COL-101 is an adiabatic, flash distillation column made of carbon steel. The function of this column is to separate the effluent from the dehydrocyclization process into aromatics and light products (methane, hydrogen, nitrogen, carbon monoxide, carbon dioxide). The column is operated at -30 F and kept at that temperature by a propane refrigeration unit. The column operates at 44 psia. The overhead and bottoms products leave at a temperature and pressure of -30 F and 44 psia, respectively (S-125 and S-124 respectively). The height of the column was 18 ft and the diameter was 35 ft. Total cost of the column was $1.12 million.

COL-201 is a multistage distillation column that is primarily used to separate a pure benzene product from the rest of the aromatics. It contains 34 stages with an assumed 70% tray efficiency. The feed (S-205) enters above stage 17 at 204,221 lb/hr. The condenser of the column operates at 30 psia with a 0.15 psia drop for each stage. The molar reflux ratio of the column is 1.0. The distillation column has two outputs: S-206, a 97.2 mol% pure benzene stream that flows at 137,508 lb/hr, and a 66,714 lb/hr stream of toluene, xylene, and naphthalene that continues through the separation train. The benzene product comes out at 222 F and 30 psia. The bottoms product, S-207 exits at 388 F and 35 psia. The height and diameter of the column were 78 ft and 11 ft, respectively. Total cost of the column itself was $1,859,105, and the column cost with all its components is $2.5 million.

COL-202 is a carbon steel multistage distillation column whose chief function is to separate toluene that will be sent to alkylation from xylene and naphthalene. The column has 33 stages, with the feed entering above stage 27. The feed, S-207 has a flow rate of 66,713 lb/hr. Each tray is assumed to be 70% efficient. The molar reflux ratio of the column is 5.0. The condenser operates at 20 psia with a 0.15 psia pressure drop in each stage. The xylene and naphthalene rich stream, S-209, leaves at 429 F and 35 psia and has a flow rate of 55,012 lb/hr. The overhead product, S-208, is 99.9% toluene and leaves at 252 F and 20 psia and a flow rate of 11,702 lb/hr. The column alone costs $769,152. The column had a 76 ft height and 5 ft diameter. The column cost with all of the components is $1.08 million.

COL-203 is a multistage distillation column made of carbon steel whose function is to separate mixed xylenes, specifically paraxylene, from naphthalene. The flow rate of the feed stream, S-210 is 55,012 lb/hr. The column has 14 stages and the feed enters above stage 9. The molar reflux ratio of the column is 3.1. The trays are assumed to be 70% efficient. The column operates at 14.7 psia with a 0.15 psia drop with each tray. The overhead product, S-212, is at 278 F and 15 psia, and is 92.4 mol% paraxylene. The flow rate of the overhead is 5120 lb/hr. The bottoms naphthalene product, S-212, is released at 434 F and 17 psia. The naphthalene product comes out at 49,891 lb/hr and is 99.7 mol% pure. The cost of the column alone is $327,172. The diameter of the column is 3.2 ft and the height is 38 ft. The column with all of its components is approximately $545,000

Decanters

D-301 is an adiabatic decanter run at 181 F and the outlet pressure is 29 psia. The feed stream, S-307, comes in at a rate of 16,729 lb/hr. Because the vapor fraction is set to 0, the decanter undergoes a temperature - vapor flash. S-309 outlet stream, which leaves at 181 F and

29 psia, is sent back to COL-201. The flow rate of that stream is 12,635 lb/hr. Additionally, a water-methanol stream is released at 60 F and 1 psia and is recycled for alkylation. The flow rate of the water-methanol stream, S-310, 4094 lb/hr. The horizontal vessel is made of carbon steel and is 15.5 ft long and 5.2 ft in diameter. The total cost of the decanter is $89,000.

Compressors

C-101 is a cast iron/carbon steel centrifugal compressor. C-101 functions to compress the gas in S-103, which is composed of the natural gas feed and recycle stream from COL-101. S-103 has a flow rate of 809,643 lb/hr and is at -12 F and 28 psia. The outlet stream S-104, comes out at 91 psia and 160 F. The compressor is isentropic and operates at 85% efficiency. The electricity consumed by the compressor is 21.7 MW and the horsepower required is 29,000 hp. The compressor cost was estimated to be $17.8 million.

C-102 is a cast iron/carbon steel centrifugal compressor. C-101 functions to compress the gas in S-105, which is composed of the natural gas feed and recycle stream from COL-101. S-105 has a flow rate of 809,643 lb/hr and is at -12 F and 28 psia. The outlet stream S-104, comes out at 91 psia and 160 F. The compressor is isentropic and operates at 85% efficiency. The electricity consumed by the compressor is 21.7 MW and the horsepower required is 29,000 hp. The compressor cost was estimated to be $17.8 million.

C-103 is a cast iron/carbon steel centrifugal compressor. C-101 functions to compress the gas in S-107, which is composed of the natural gas feed and recycle stream from COL-101. S-107 has a flow rate of 809,643 lb/hr and is at -12 F and 28 psia. The outlet stream S-104, comes out at 91 psia and 160 F. The compressor is isentropic and operates at an 85% efficiency. The electricity consumed by the compressor is 21.7 MW and the horsepower required is 29,000 hp. The compressor cost was estimated to be $17.8 million.

C-104 is a centrifugal, cast iron-carbon steel compressor fed at a rate of 809,455 lb/hr. The function of C-104 is to compress S-114 from 250 F and 27 psia to 471 F and 90 psia. The electricity consumption required by the compressor was 33.4 MW and the net work required was 45,000 hp. The compressor is made of cast iron/carbon steel and is a centrifugal compressor. The compressor operates isentropically with an 85% efficiency. The total cost of the compressor was $25.1 million

C-105 is a centrifugal, cast iron-carbon steel compressor fed at a rate of 809,455 lb/hr. The function of C-105 is to compress S-116 from 250 F and 27 psia to 471 F and 90 psia. The electricity consumption required by the compressor was 33.4 MW and the net work required was 45,000 hp. The compressor is made of cast iron/carbon steel and is a centrifugal compressor. The compressor operates isentropically with an 85% efficiency. The total cost of the compressor was $25.1 million.

C-106 is a centrifugal, cast iron-carbon steel compressor fed at a rate of 809,455 lb/hr. The function of C-106 is to compress S-118 from 250 F and 27 psia to 471 F and 90 psia. The electricity consumption required by the compressor was 33.4 MW and the net work required was 45,000 hp. The compressor is made of cast iron/carbon steel and is a centrifugal compressor. The compressor operates isentropically with an 85% efficiency. The total cost of the compressor was $25.1 million

C-401 is a centrifugal, cast iron-carbon steel compressor fed at a rate of 78,268 lb/hr. The function of C-401 is to compress S-403 from -32 F and 28 psia to 29 F and 44 psia. The electricity consumption required by the compressor was 732 kW and the net work required was 982 hp. The compressor is made of cast iron/carbon steel and is a centrifugal compressor. The compressor operates isentropically with an 85% efficiency. The total cost of the compressor was approximately $1.18 million.

C-402 is a centrifugal, cast iron-carbon steel compressor fed at a rate of 2.2 MMlb/hr. The function of C-402 is to compress S-406 from 86 F and 14.7 psia to 321 F and 44 psia. The electricity consumption required by the compressor was 33.7 MW and the net work required was 45,000 hp. The compressor is made of cast iron/carbon steel and is a centrifugal compressor. The compressor operates isentropically with an 85% efficiency. The total cost of the compressor was $25.3 million

Turbines

T-401 is a turbine whose chief function is to generate steam from S-413, which is at a temperature and pressure of 543 F and 400 psia respectively. The output temperature and pressure of the turbine are 217 F and 15 psia. The turbine operates at an 85% isentropic efficiency and has net work of 49,000 hp. Final cost of the turbine will be $1.23 million

T-402 is a turbine whose chief function is to generate steam from S-415, which is at a temperature and pressure of 543 F and 400 psia respectively. The output temperature and pressure of the turbine are 217 F and 15 psia. The turbine operates at an 85% isentropic efficiency and has net work of 49,000 hp. Final cost of the turbine will be $1.23 million

T-403 is a turbine whose chief function is to generate steam from S-417, which is at a temperature and pressure of 543 F and 400 psia respectively. The output temperature and pressure of the turbine are 217 F and 15 psia. The turbine operates at an 85% isentropic efficiency and has net work of 49,000 hp. Final cost of the turbine will be $1.23 million

Pumps

P-201 is a cast iron, centrifugal pump. The capacity of the pump is 3810 cuft/hr and the pressure increase is 37 psia. The function of this pump is to pressurize the inlet stream before it enters COL-202.The inlet stream (S-204) has a flow rate of 204,221 lb/hr and a temperature and pressure of 171 F and 13 psia respectively. The electricity required for this pump is 10.8 kW and the efficiency is 71%. The outlet stream S-205 is at 50 psia ad 171 F. The net work required is 14.5 hp. The cost of the pump is approximately $15,700

P-202 is a cast iron, centrifugal pump. The capacity of the pump is 1057 cuft/hr and the pressure increase is 16 psia. The function of this pump is to pressurize the inlet stream before it enters COL-203.The inlet stream (S-209) has a flow rate of 55,012 lb/hr and a temperature and pressure of 429 F and 25 psia respectively. The electricity required for this pump is 1.61 kW and the efficiency is 57%. The outlet stream S-209 is at 41 psia ad 429 F. The net work required is 2.2 hp. The cost of the pump is $11,400.

P-203 is a cast iron, centrifugal pump. The capacity of the pump is 109 cuft/hr and the pressure increase is 32 psia. The inlet stream (S-211) has a flow rate of 5120 lb/hr and a temperature and pressure of 278 F and 15 psia respectively. The electricity required for this pump is 0.64 kW and the efficiency is 30%. The net work required is .9 hp. The outlet stream S-213 is at 47 psia ad 278 F. The cost of the pump is $11,309.

P-204 is a cast iron, centrifugal pump. The capacity of the pump is 938 cuft/hr and the pressure increase is 34 psia. The inlet stream (S-212) has a flow rate of 49,892 lb/hr and a temperature and pressure of 434 F and 17 psia respectively. The electricity required for this pump is 3.1 kW and the efficiency is 55%. The outlet stream S-218 is at 51 psia ad 434 F. The net work required is 4.2 hp. The cost of the pump is approximately $11,700.

P-301 is a cast iron, centrifugal pump. The capacity of the pump is 334 cuft/hr and the pressure increase is 32 psia. The inlet stream (S-301) has a flow rate of 16,729 lb/hr and a temperature and pressure of 142 F and 20 psia respectively. The electricity required for this pump is 0.83 kW and the efficiency is 70%. The net work required is 1.1 hp. The outlet stream S-302 is at 52 psia and 142 F. The cost of the pump is approximately $10,870.

P-302 is a cast iron, centrifugal pump. The capacity of the pump is 325 cuft/hr and the pressure increase is 32 psia. The inlet stream (S-301) has a flow rate of 16,729 lb/hr and a temperature and pressure of 117 F and 6 psia respectively. The electricity required for this pump is 0.96 kW and the efficiency is 70%. The net work required is 1.2hp. The outlet stream S-302 is at 44 psia and 117 F. The cost of the pump is $10,880.

P-401 is a cast iron, centrifugal pump. The capacity of the pump is 7009 cuft/hr and the pressure increase is 385 psia. The inlet stream (S-410) has a flow rate of 414,351 lb/hr and a temperature and pressure of 106 F and 14.7 psia respectively. The electricity required for this pump is 193 kW and the efficiency is 76%. The outlet stream S-411 is at 400 psia ad 106 F. The net work required is 258 hp. The cost of the pump is approximately $44,820

P-Reb-COL-201 is a cast iron, centrifugal pump whose function is to increase the pressure in the reboiler of COL-201 by 10 psia. The pump had a flow rate of 162 gpm and a 280 ft head. Total purchase cost for this pump is approximately $13,700.

P-Reb-COL-202 is a cast iron, centrifugal pump whose function is to increase the pressure in the reboiler of COL-202 by 10 psia. The pump had a flow rate of 132 gpm and a 277 ft head. Total purchase cost for this pump is approximately $13,070.

P-Reb-COL-203 is a cast iron, centrifugal pump whose function is to increase the pressure in the reboiler of COL-203 by 10 psia. The pump had a flow rate of 117 gpm and a 271 ft head. Total purchase cost for this pump is approximately $12,800

P-Cond-COL-201 is a cast iron, centrifugal pump whose function is to increase the pressure in the condenser of COL-201 by 10 psia. The pump had a flow rate of 350 gpm and a 294 ft head. Total purchase cost for this pump is approximately $16,800.

P-Cond-COL-202 is a cast iron, centrifugal pump whose function is to increase the pressure in the condenser of COL-202 by 10 psia. The pump had a flow rate of 31 gpm and a 301 ft head. Total purchase cost for this pump is approximately $11,000.

P-Cond-COL-203 is a cast iron, centrifugal pump whose function is to increase the pressure in the condenser of COL-203 by 10 psia. The pump had a flow rate of 14 gpm and a 307 ft head. Total purchase cost for this pump is approximately $10,900.

Reflux Accumulators

RA-COL-201 is the reflux accumulator for COL-201. It has a diameter and length of 8.4 ft and 17 ft. The capacity of the accumulator is 931 ft^3 and has a residence time of 5 minutes. Total cost of the reflux accumulator is approximately $144,200.

RA-COL-202 is the reflux accumulator for COL-202. It has a diameter and length of 5.4 ft and 11 ft. The capacity of the accumulator is 252 ft^3 and has a residence time of 5 minutes. Total cost of the reflux accumulator is approximately $81,000.

RA-COL-203 is the reflux accumulator for COL-203. It has a diameter and length of 3.9 ft and 7.6 ft. The capacity of the accumulator is 86 ft^3 and has a residence time of 5 minutes. Total cost of the reflux accumulator is approximately $57,000.

Column Condensers

C-COL-201 is the overhead condenser in COL-201. It is made of carbon steel and has a length of 20 ft and surface area of 2390 ft^2. The duty of the condenser is $4.5*10^7$ BTU/hr and the condenser operates at 30 psia. Total cost of the condenser is $85,900.

C-COL-202 is the overhead condenser in COL-202. It is made of carbon steel and has a length of 20 ft and surface area of 467 ft^2. The duty of the condenser is $1.1*10^8$ BTU/hr and the condenser operates at 20 psia. Total cost of the condenser is $41,170.

C-COL-203 is the overhead condenser in COL-203. It is made of carbon steel and has a length of 20 ft and surface area of 134 ft^2. The duty of the condenser is $3.7*10^6$ BTU/hr and the condenser operates at 30 psia. Total cost of the condenser is approximately $33,500.

Column Reboilers

Reb-COL-201 is the bottoms reboiler in COL-201. It is made of carbon steel and has a length of 20 ft and surface area of 6,270 ft^2. The duty of the reboiler is $5.6*10^7$ BTU/hr. The reboiler is heated by H-406. Total cost of the reboiler is $346,000.

Reb-COL-202 is the bottoms reboiler in COL-202. It is made of carbon steel and has a length of 20 ft and surface area of 1,702 ft^2. The duty of the reboiler is $1.1*10^8$ BTU/hr. The reboiler is heated by H-405. Total cost of the reboiler is $161,000.

Reb-COL-203 is the bottoms reboiler in COL-203. It is made of carbon steel and has a length of 20 ft and surface area of 492 ft^2. The duty of the reboiler is $3.3*10^7$ BTU/hr. The reboiler is heated by H-404. Total cost of the reboiler is $104,000.

Reactors

R-101 is an adiabatic, fixed bed, catalytic reactor. The purpose of R-101 is to make the natural gas feed undergo a dehydrocyclization process. The reactor has a length of 30 ft and a diameter of 15 ft. The temperature of the reaction is 1440 F at the inlet stream S-111 is at 59 psia. A pressure drop of 10 psia was calculated, but 15 psia was used in the simulation for a conservative estimate. The reaction is endothermic and molybdenum-zeolite catalyst supports the reaction for up to 48 hrs. The volumetric flow rate of the reactor is 3000 ml/g-cat/hr. Each reactor requires 126,424 kg catalyst/yr. The outlet stream S-112 leaves at 1239 F and 43 psia. The flow rate through the reactor is 2.4 MMlb/hr. The total cost for each reactor is $680,220. Our plant will have 3 reactors, for a total cost of $2.04 MM.

R-301 is an adiabatic, fluidized, catalytic reactor. R-301 serves to alkylate toluene to paraxylene, a major product for the plant. S-303, the inlet to the reactor is at 1105 F and 45 psia. The alkylation is an exothermic reactor, and the outlet leaves at 1231 F and 28 psia. The flow rate through the reactor is 16,729 lb/hr. The reactor requires 6100 kg/yr of catalyst. The diameter of the reactor is 6.9 ft and the length is 13.8 ft. The WHSV of the catalyst is 1.2 hr^{-1}. The total cost of the reactor is $218,967.

Heat Exchangers

H-101 and H-103 are shown as two units, but in reality will be designed as the same heat exchanger. The exchanger serves to use the heat in the effluent of the dehydrocyclization reactor to heat the feed stream. The cold stream (S-109) goes from 160 F to 1172 F, and the hot stream (S-112) goes from 1239 F to 250 F. The flow rate across the heat exchanger is 2.4MM lb/hr at an inlet pressure of 91 psia. Due to pressure drops in the exchanger and reactor, the exit of this exchanger (S-113) is at 27 psia. Due to the high flow rate and high required temperature rise of the cold stream, the duty for this exchanger is 1.90×10^9 BTU/hr. Using a U value of 150 BTU/hr-ft^2-R, this exchanger requires 11 units each of at least 14,800 ft^2 to accomplish the temperature rise. The cost for these exchangers $3,550,000 for 11 units.

H-102 and H-401 are shown as two units, but, like H-101 and H-103, will be designed as the same heat exchanger. Since H-101/H-103 is not enough to heat the feed to the dehydrocyclization reactor to the required temperature of 1440 F, extra heat is required. This is accomplished using the heat from F-101. The cold stream (S-110) goes from 1172 F to 1440 F, and the hot stream (S-407) goes from 2450 F to 1459 F. The flow rate across the heat exchanger for the process stream is 2.1MM lb/hr at an inlet pressure of 75 psia. Due to pressure drops in the exchanger, the exit of this exchanger (S-113) is at 59 psia. Due to the high flow rate of the cold stream, the duty for this exchanger is 660MM BTU/hr. This exchange is accomplished using one unit with a transfer coefficient of 150 BTU/hr-ft^2-R and a surface area of 7,600 ft^2 for a bare-module cost of $295,000.

H-104 and H-107 are shown as two units, but will also be designed as the same heat exchanger. This exchanger serves to cool the feed to COL-101 as much as possible using the cooling ability of the bottoms product of the flash. The cold stream (S-124), which has a flow rate and inlet pressure of 192,000 lb/hr and 28 psia, respectively, goes from -32 F to 170 F. The hot stream (S-120), with a flow rate of 2.4MM lb/hr and an inlet pressure of 90 psia is cooled from 472 F to 463 F. The duty of the exchanger is 15MM BTU/hr. This exchange is accomplished using one unit transfer coefficient of 125 BTU/hr-ft2-R and a surface area of 315 ft^2 for a bare-module cost of $70,000.

H-105 is the first exchanger in the process involving cooling water. This exchanger serves to cool the feed to COL-101 as much as possible using cooling water. The hot stream (S-121), with a flow rate of 2.4MM lb/hr and an inlet pressure of 74 psia is cooled from 463 F to 110 F. The cooling water has a flow rate of 290MM gal/hr and goes from 86 F to 106 F. The duty of the exchanger is 530MM BTU/hr. This exchange is accomplished using three units with a transfer coefficient of 150 BTU/hr-ft^2-R of 9,600 ft^2 each for a unit bare-module cost of $351,000, or a total of $1.05MM for the three units.

H-106 is the propane refrigeration unit that serves to cool the feed to COL-101 to the required temperature of -31 F. The flow rate through this unit is 2.4MM lb/hr. The inlet stream (S-122) goes from 110 F and 59 psia to -30 F and 44 psia (a pressure drop of 15 psia was assumed). This exchanger is purchased as a unit for a cost of $30.6 million and requires 60 MW to operate.

H-201 is also a heat exchanger the employs cooling water, similarly to H-105. This exchanger serves to cool the distillate product of COL-203 to ambient conditions so that it can be stored. The hot stream (S-213), with a flow rate of 5120 lb/hr and an inlet pressure of 47 psia is cooled from 278 F to 110 F. The cooling water has a flow rate of 2200 gal/hr and goes from 86 F to 106 F. The duty of the exchanger is 400,000 BTU/hr. This exchange is accomplished using a unit with a transfer coefficient of 150 BTU/hr-ft^2-R and a surface area 150 ft^2 for a unit bare-module cost of $65,000.

H-202 works similarly to H-201, but instead serves to cool the bottoms product of COL-203 to ambient conditions for storage. The hot stream (S-218), with a flow rate of 50,000 lb/hr and an inlet pressure of 51 psia is cooled from 434 F to 110 F. The cooling water has a flow rate of 38,000 gal/hr and goes from 86 F to 106 F. The duty of the exchanger is 7MM BTU/hr. This exchange is accomplished using a unit with a transfer coefficient of 150 BTU/hr-ft^2-R and a surface area of 400 ft^2 for a unit bare-module cost of $73,000.

H-203 and H-407 is another pair of models that will be designed as one unit. This exchanger serves to heat the PX product stream to ambient conditions in order to liquefy it to be transported and stored. The stream used to heat the PX product is the water that exits the turbine after the energy of the steam has been captured in Section IV. The cold stream (S-216) has a flow rate of 4,100 lb/hr and goes from -13 F to 100 F. The hot stream (S-419) has a flow rate of

414,000 lb/hr and goes from 217 F to 188 F. This exchanger is modeled as a shell-and-tube exchanger using a transfer coefficient of 50 BTU/hr-ft^2-R due to the presence of a solid stream (the PX product) being heated by a stream that is almost all vapor (the exit of the turbines). The duty on this exchanger is 178,000 BTU/hr. This exchange is accomplished in one unit with a surface area of 150 ft^2 and a bare module cost of $65,000.

H-301 and H-302 is the last pair of models that we will be designed as one exchanger unit. This exchanger operates in the same fashion as H-101 and H-103, where the unit is used to heat the feed to a reactor with the heat of the effluent stream. Since the alkylation reaction is exothermic, there is enough heat available to heat the feed to the required temperature. The cold stream (S-302) has a flow rate of 17,000 lb/hr and goes from 142 F to 1105 F. The hot stream (S-304) has the same flow rate and goes from 1231 F to 178 F. The duty of the unit is 12.8MM BTU/hr. The exchanger is modeled with a transfer coefficient of 100 BTU/hr-ft^2-R and has a surface area of 1750 ft^2. The bare-module cost for this unit is $121,000.

H-303 is also an exchanger that uses cooling water to cool a process stream, similarly to H-201 and H-202. The hot stream (S-305), with a flow rate of 17,000 lb/hr and an inlet pressure of 21 psia is cooled from 178 F to 117 F. The cooling water has a flow rate of 9,000 gal/hr and goes from 86 F to 106 F. The duty of the exchanger is 1.6MM BTU/hr. This exchange is accomplished using a unit with a transfer coefficient of 100 BTU/hr-ft^2-R and a surface area of 336 ft^2 for a unit bare-module cost of $71,000.

H-402 and H-408 are simulated as separate units but will also be designed as one, like to H-101 and H-103. This unit serves to heat S-402 to near-ambient conditions so that it can be sold. This stream also serves to cool the furnace effluent. The hot stream (S-408) has a flow rate of 2.1MM lb/hr and starts at 1495 F and exits at 1384 F. The cold stream (S-401) has a flow rate of 370,000 lb/hr enters at -32 F and exits at 200 F. This exchange is accomplished by one unit with a transfer coefficient of 100 BTU/hr-ft^2-R, which is lower than average since heat is being exchanged between two vapor streams. The unit has an area of 358 ft^2 and a bare-module cost of $71,500.

H-403 is the steam generator for the turbines in Section IV. After the dehydrocyclization feed is heated to the required temperature, the resulting temperature of S-409 is still too high to be used in our reboilers, so the excess heat is used to generate steam to power turbines and generate electricity. The hot stream (S-409), with a flow rate of 3MM lb/hr and an inlet pressure of 30 psia is cooled from 1384 F to 501 F. The steam is generated from cooling water that has already been used elsewhere in the process, which has a flow rate of 23,000 gal/hr and goes from 106 F and 400 psia to 543 F and 400 psia. The duty of the exchanger is 530MM BTU/hr. This exchange is done with a packaged boiler, totaling $2.29 million.

Crystallizer

CRY-201 is a crystallizer, whose primary function is to purify S-215 by forming solid, paraxylene crystals. The unit requires 7 crystallizers, each 185 ft in length. The duty for the crystallizers is 25 BTU/hr. Total costs for all the units is $7,850,000.

Specification Sheets

COLUMN			
Identification: COL-101			
Function: To separate aromatics from light components in S-123			
Operation: Continuous			
Material Handled			
	S-123	**S-124**	**S-125**
Mass Composition			
Benzene	0.062	0.696	0.008
Toluene	0.003	0.041	0.000
P-xylene	0.000	0.000	0.000
M-xylene	0.000	0.000	0.000
O-xylene	0.000	0.000	0.000
Methanol	0.000	0.000	0.000
Water	0.000	0.000	0.000
Methane	0.770	0.001	0.836
Nitrogen	0.021	0.000	0.023
Hydrogen	0.021	0.000	0.023
Carbon Monoxide	0.002	0.000	0.002
Carbon Dioxide	0.100	0.002	0.109
Naphthalene	0.020	0.259	0.000
Oxygen	0.000	0.000	0.000
Air	0.000	0.000	0.000
Total Flow Rate (lb/hr)	**2,420,000**	**192,156**	**2,200,000**
Design Data:			
	Material	Carbon Steel	
	Diameter (ft)	35	
	Length (ft)	18	
	Outlet Temperature (F)	-31	
	Outlet Pressure (psia)	28	
Total Bare Module Cost (USD)	1,119,992		

DISTILLATION COLUMN			
Identification: COL-201			
Function: To separate benzene from other components in S-205			
Operation: Continuous			
Material Handled			
	S-205	**S-207**	**S-206**
Composition			
Benzene	0.654	0.000	0.972
Toluene	0.076	0.179	0.026
P-xylene	0.024	0.073	0.000
M-xylene	0.000	0.001	0.000
O-xylene	0.000	0.001	0.000
Methanol	0.001	0.000	0.002
Water	0.000	0.000	0.000
Methane	0.000	0.000	0.000
Nitrogen	0.000	0.000	0.000
Hydrogen	0.000	0.000	0.000
Carbon Monoxide	0.000	0.000	0.000
Carbon Dioxide	0.000	0.000	0.000
Naphthalene	0.244	0.746	0.000
Oxygen	0.000	0.000	0.000
Air	0.000	0.000	0.000
Total Flow Rate (lb/hr)	**204,221**	**66,713**	**137,508**
Design Data:			
Number of Trays	33	Feed Stage	16
Condenser Temperature (F)	222	Reflux Ratio	1
Reboiler Temperature (F)	388	Tray Type	Bubble Cap
Height (ft)	78	Condenser Pressure (psia)	30
Diameter (ft)	11	Reboiler Pressure (psia)	35
Material	Carbon Steel	Stage Pressure Drop (psia)	0.15
Tray Efficiency	70%	Condenser Duty (BTU/hr)	4.50E+07
Tray Spacing (ft)	2	Reboiler Duty (BTU/hr)	5.50E+07
Total Bare Module Cost (USD)	1,859,105		

DISTILLATION COLUMN			
Identification: COL-202			
Function: To separate toluene from other components in S-207			
Operation: Continuous			
Material Handled			
	S-207	**S-209**	**S-208**
Mass Composition			
Benzene	0.000	0.000	0.000
Toluene	0.179	0.005	1.000
P-xylene	0.073	0.088	0.000
M-xylene	0.001	0.001	0.000
O-xylene	0.001	0.001	0.000
Methanol	0.000	0.000	0.000
Water	0.000	0.000	0.000
Methane	0.000	0.000	0.000
Nitrogen	0.000	0.000	0.000
Hydrogen	0.000	0.000	0.000
Carbon Monoxide	0.000	0.000	0.000
Carbon Dioxide	0.000	0.000	0.000
Naphthalene	0.746	0.905	0.000
Oxygen	0.000	0.000	0.000
Air	0.000	0.000	0.000
Total Flow Rate (lb/hr)	**66,713**	**55,012**	**11,702**
Design Data:			
Number of Trays	32	Feed Stage	26
Condenser Temperature	252	Reflux Ratio	5
Reboiler Temperature	429	Tray Type	Bubble Cap
Height (ft)	76	Condenser Pressure (psia)	20
Diameter (ft)	5	Reboiler Pressure (psia)	25
Material	Carbon Steel	Stage Pressure Drop (psia)	0.15
Tray Efficiency	70%	Condenser Duty (BTU/hr)	1.09E+08
Tray Spacing (ft)	2	Reboiler Duty (BTU/hr)	1.12E+08
Total Bare Module Cost (USD)	769,152		

DISTILLATION COLUMN			
Identification: COL-203			
Function: To separate p-xylene from other components in S-210			
Operation: Continuous			
Material Handled			
	S-210	**S-211**	**S-212**
Composition			
Benzene	0.000	0.000	0.000
Toluene	0.005	0.000	0.052
P-xylene	0.088	0.002	0.924
M-xylene	0.001	0.000	0.012
O-xylene	0.001	0.000	0.012
Methanol	0.000	0.000	0.000
Water	0.000	0.000	0.000
Methane	0.000	0.000	0.000
Nitrogen	0.000	0.000	0.000
Hydrogen	0.000	0.000	0.000
Carbon Monoxide	0.000	0.000	0.000
Carbon Dioxide	0.000	0.000	0.000
Naphthalene	0.905	0.997	0.001
Oxygen	0.000	0.000	0.000
Air	0.000	0.000	0.000
Total Flow Rate (lb/hr)	**55,012**	**49,892**	**5,120**
Design Data:			
Number of Trays	13	Feed Stage	8
Condenser Temperature	278	Reflux Ratio	3.1
Reboiler Temperature	433	Tray Type	Bubble Cap
Height (ft)	38	Condenser Pressure (psia)	15
Diameter (ft)	3.2	Reboiler Pressure (psia)	17
Material	Carbon Steel	Stage Pressure Drop (psia)	0.15
Tray Efficiency	70%	Condenser Duty (BTU/hr)	3.64E+06
Tray Spacing (ft)	2	Reboiler Duty (BTU/hr)	3.32E+07
Total Bare Module Cost (USD)	327,172		

DECANTER				
Identification: D-301				
Function: To separate methanol and water from BTX from the input provided by S-307				
Operation: Continuous				
Material Handled				
	S-307	**S-308**	**S-309**	**S-310**
Mass Composition				
Benzene	0.000	0.000	0.000	0.000
Toluene	0.454	0.000	0.595	0.020
P-xylene	0.287	0.000	0.379	0.003
M-xylene	0.000	0.000	0.000	0.000
O-xylene	0.000	0.000	0.000	0.000
Methanol	0.110	0.000	0.024	0.378
Water	0.148	0.000	0.002	0.599
Methane	0.000	0.000	0.000	0.000
Nitrogen	0.000	0.000	0.000	0.000
Hydrogen	0.000	0.000	0.000	0.000
Carbon Monoxide	0.000	0.000	0.000	0.000
Carbon Dioxide	0.000	0.000	0.000	0.000
Naphthalene	0.000	0.000	0.000	0.000
Oxygen	0.000	0.000	0.000	0.000
Air	0.000	0.000	0.000	0.000
Total Flow Rate (lb/hr)	**16,729**	**0**	**12,635**	**4,094**
Design Data:				
	Material	Carbon Steel		
	Diameter (ft)	5.2		
	Length (ft)	15.5		
	Capacity (ft^3)	329.0		
	Temperature (F)	178		
	Operating Pressure (psig)	14.3		
Total Bare Module Cost (USD)	89,273			

COMPRESSOR		
Identification: C-101		
Function: To increase the pressure from stream S-103 from 28 psia to 91 psia		
Operation: Continuous		
Design Data:		
	Type	Centrifugal
	Driver Type	Electric Motor
	Material	Cast Iron / Carbon Steel
	Input Pressure (psia)	28
	Outlet Pressure (psia)	91
	Input Temperature (F)	-12
	Outlet Temperature (F)	160
	Flow Rate (lb/hr)	809,463
	Efficiency	85%
	Driver Power (hp)	29,137
Utilities	Electricity (kW)	21,728
Total Bare Module Cost (USD)	17,805,770	

COMPRESSOR		
Identification: C-102		
Function: To increase the pressure from stream S-105 from 28 psia to 91 psia		
Operation: Continuous		
Design Data:		
	Type	Centrifugal
	Driver Type	Electric Motor
	Material	Cast Iron / Carbon Steel
	Input Pressure (psia)	28
	Outlet Pressure (psia)	91
	Input Temperature (F)	-12
	Outlet Temperature (F)	160
	Flow Rate (lb/hr)	809,463
	Efficiency	85%
	Driver Power (hp)	29,137
Utilities	Electricity (kW)	21,728
Total Bare Module Cost (USD)	17,805,770	

COMPRESSOR		
Identification: C-103		
Function: To increase the pressure from stream S-107 from 28 psia to 91 psia		
Operation: Continuous		
Design Data:		
	Type	Centrifugal
	Driver Type	Electric Motor
	Material	Cast Iron / Carbon Steel
	Input Pressure (psia)	28
	Outlet Pressure (psia)	91
	Input Temperature (F)	-12
	Outlet Temperature (F)	160
	Flow Rate (lb/hr)	809,463
	Efficiency	85%
	Driver Power (hp)	29,137
Utilities	Electricity (kW)	21,728
Total Bare Module Cost (USD)	17,805,770	

COMPRESSOR		
Identification: C-104		
Function: To increase the pressure from stream S-114 from 27 psia to 90 psia		
Operation: Continuous		
Design Data:		
	Type	Centrifugal
	Driver Type	Electric Motor
	Material	Cast Iron / Carbon Steel
	Input Pressure (psia)	27
	Outlet Pressure (psia)	90
	Input Temperature (F)	250
	Outlet Temperature (F)	471
	Flow Rate (lb/hr)	809,455
	Efficiency	85%
	Driver Power (hp)	33,436
Utilities	Electricity (kW)	33,436
Total Bare Module Cost (USD)	25,137,732	

COMPRESSOR		
Identification: C-105		
Function: To increase the pressure from stream S-116 from 27 psia to 90 psia		
Operation: Continuous		
Design Data:		
	Type	Centrifugal
	Driver Type	Electric Motor
	Material	Cast Iron / Carbon Steel
	Input Pressure (psia)	27
	Outlet Pressure (psia)	90
	Input Temperature (F)	250
	Outlet Temperature (F)	471
	Flow Rate (lb/hr)	809,455
	Efficiency	85%
	Driver Power (hp)	33,436
Utilities	Electricity (kW)	33,436
Total Bare Module Cost (USD)	25,137,732	

COMPRESSOR		
Identification: C-106		
Function: To increase the pressure from stream S-118 from 27 psia to 90 psia		
Operation: Continuous		
Design Data:		
	Type	Centrifugal
	Driver Type	Electric Motor
	Material	Cast Iron / Carbon Steel
	Input Pressure (psia)	27
	Outlet Pressure (psia)	90
	Input Temperature (F)	250
	Outlet Temperature (F)	471
	Flow Rate (lb/hr)	809,455
	Efficiency	85%
	Driver Power (hp)	33,436
Utilities	Electricity (kW)	33,436
Total Bare Module Cost (USD)	25,137,732	

COMPRESSOR		
Identification: C-401		
Function: To increase the pressure from stream S-403 from 28 psia to 44 psia		
Operation: Continuous		
Design Data:		
	Type	Centrifugal
	Driver Type	Electric Motor
	Material	Cast Iron / Carbon Steel
	Input Pressure (psia)	28
	Outlet Pressure (psia)	44
	Input Temperature (F)	-32
	Outlet Temperature (F)	29
	Flow Rate (lb/hr)	78,268
	Efficiency	85%
	Driver Power (hp)	982
Utilities	Electricity Required (kW)	732
Total Bare Module Cost (USD)	1,182,205	

COMPRESSOR		
Identification: C-402		
Function: To increase the pressure from stream S-405 from 15 psia to 44 psia		
Operation: Continuous		
Design Data:		
	Type	Centrifugal
	Driver Type	Electric Motor
	Material	Cast Iron / Carbon Steel
	Input Pressure (psia)	15
	Outlet Pressure (psia)	44
	Input Temperature (F)	86
	Outlet Temperature (F)	321
	Flow Rate (lb/hr)	2.02E+07
	Efficiency	85%
	Driver Power (hp)	45,249
Utilities	Electricity Required (kW)	33,742
Total Bare Module Cost (USD)	25,321,584	

TURBINE		
Identification: T-401		
Function: To generate steam from S-413		
Operation: Continuous		
Design Data:		
	Type	Electrical
	Material	Carbon Steel
	Input Pressure (psia)	400
	Outlet Pressure (psia)	15
	Input Temperature (F)	543
	Outlet Temperature (F)	217
	Flow Rate (lb/hr)	138,117
	Efficiency	85%
	Driver Power (hp)	12,261
Utilities		
Total Bare Module Cost (USD)	1,231,946	

TURBINE		
Identification: T-402		
Function: To generate steam from S-415		
Operation: Continuous		
Design Data:		
	Type	Electrical
	Material	Carbon Steel
	Input Pressure (psia)	400
	Outlet Pressure (psia)	15
	Input Temperature (F)	543
	Outlet Temperature (F)	217
	Flow Rate (lb/hr)	138,117
	Efficiency	85%
	Driver Power (hp)	12,261
Utilities		
Total Bare Module Cost (USD)	1,231,946	

TURBINE		
Identification: T-403		
Function: To generate steam from S-417		
Operation: Continuous		
Design Data:		
	Type	Electrical
	Material	Carbon Steel
	Input Pressure (psia)	400
	Outlet Pressure (psia)	15
	Input Temperature (F)	543
	Outlet Temperature (F)	217
	Flow Rate (lb/hr)	138,117
	Efficiency	85%
	Driver Power (hp)	12,261
Utilities		
Total Bare Module Cost (USD)	1,231,946	

PUMP		
Identification: P-201		
Function: To increase the pressure from stream S-204 from 13 psia to 50 psia		
Operation: Continuous		
Design Data:		
	Type	Centrifugal
	Material	Cast Iron
	Input Pressure (psia)	13
	Outlet Pressure (psia)	50
	Flow Rate (lb/hr)	204,221
	Efficiency	71%
	Net Work (hp)	14.5
Utilities	Electricity Required (kW)	11
Total Bare Module Cost (USD)	15,679	

PUMP		
Identification: P-202		
Function: To increase the pressure from stream S-209 from 24.8 psia to 40.8 psia		
Operation: Continuous		
Design Data:		
	Type	Centrifugal
	Material	Cast Iron
	Input Pressure (psia)	25
	Outlet Pressure (psia)	41
	Flow Rate (lb/hr)	55,012
	Efficiency	57%
	Net Work (hp)	2.2
Utilities	Electricity Required (kW)	1.6
Total Bare Module Cost (USD)	11,399	

PUMP		
Identification: P-203		
Function: To increase the pressure from stream S-211 from 14.7 psia to 46.7 psia		
Operation: Continuous		
Design Data:		
	Type	Centrifugal
	Material	Cast Iron
	Input Pressure (psia)	15
	Outlet Pressure (psia)	47
	Flow Rate (lb/hr)	5,120
	Efficiency	30%
	Net Work (hp)	0.9
Utilities	Electricity Required (kW)	0.6
Total Bare Module Cost (USD)	11,309	

PUMP		
Identification: P-204		
Function: To increase the pressure from stream S-212 from 17 psia to 51 psia		
Operation: Continuous		
Design Data:		
	Type	Centrifugal
	Material	Cast Iron
	Input Pressure (psia)	17
	Outlet Pressure (psia)	51
	Flow Rate (lb/hr)	48,892
	Efficiency	56%
	Net Work (hp)	4.2
Utilities	Electricity Required (kW)	3.1
Total Bare Module Cost (USD)	11,724	

PUMP		
Identification: P-301		
Function: To increase the pressure from stream S-301 from 20 psia to 52 psia		
Operation: Continuous		
Design Data:		
	Type	Centrifugal
	Material	Cast Iron
	Input Pressure (psia)	20
	Outlet Pressure (psia)	52
	Flow Rate (lb/hr)	16,729
	Efficiency	70%
	Net Work (hp)	1.1
Utilities	Electricity Required (kW)	0.8
Total Bare Module Cost (USD)	10,868	

PUMP		
Identification: P-302		
Function: To increase the pressure from stream S-306 from 6 psia to 44 psia		
Operation: Continuous		
Design Data:		
	Type	Centrifugal
	Material	Cast Iron
	Input Pressure (psia)	6
	Outlet Pressure (psia)	44
	Flow Rate (lb/hr)	16,729
	Efficiency	70%
	Net Work (hp)	1.2
Utilities	Electricity Required (kW)	0.8
Total Bare Module Cost (USD)	10,879	

PUMP		
Identification: P-401		
Function: To increase the pressure from stream S-410 from 15 psia to 400 psia		
Operation: Continuous		
Design Data:		
	Type	Centrifugal
	Material	Cast Iron
	Input Pressure (psia)	6
	Outlet Pressure (psia)	400
	Flow Rate (lb/hr)	414,351
	Efficiency	76%
	Net Work (hp)	258
Utilities	Electricity Required (kW)	193
Total Bare Module Cost (USD)	44,817	

PUMP		
Identification: P-Cond-COL-201		
Function: To increase the pressure in the condenser by 10 psia		
Operation: Continuous		
Design Data:		
	Type	Centrifugal
	Material	Cast Iron
	Pressure Increase (psia)	10
	Flow Rate (gpm)	350
	Head (ft)	294
Total Bare Module Cost (USD)	16,785	

PUMP		
Identification: P-Cond-COL-202		
Function: To increase the pressure in the condenser by 10 psia		
Operation: Continuous		
Design Data:		
	Type	Centrifugal
	Material	Cast Iron
	Pressure Increase (psia)	10
	Flow Rate (gpm)	31
	Head (ft)	301
Total Bare Module Cost (USD)	10,973	

PUMP		
Identification: P-Cond-COL-203		
Function: To increase the pressure in the condenser by 10 psia		
Operation: Continuous		
Design Data:		
	Type	Centrifugal
	Material	Cast Iron
	Pressure Increase (psia)	10
	Flow Rate (gpm)	14
	Head (ft)	307
Total Bare Module Cost (USD)	10,908	

PUMP		
Identification: P-Reb-COL-201		
Function: To increase the pressure in the reboiler by 10 psia		
Operation: Continuous		
Design Data:		
	Type	Centrifugal
	Material	Cast Iron
	Pressure Increase (psia)	10
	Flow Rate (gpm)	162
	Head (ft)	280
Total Bare Module Cost (USD)	13,654	

Operation: Continuous		
Design Data:		
	Type	Centrifugal
	Material	Cast Iron
	Pressure Increase (psia)	10
	Flow Rate (gpm)	132
	Head (ft)	277
Total Bare Module Cost (USD)	13,066	

PUMP		
Identification: P-Reb-COL-203		
Function: To increase the pressure in the reboiler by 10 psia		
Operation: Continuous		
Design Data:		
	Type	Centrifugal
	Material	Cast Iron
	Pressure Increase (psia)	10
	Flow Rate (gpm)	117
	Head (ft)	271
Total Bare Module Cost (USD)	12,746	

REFLUX ACCUMULATOR		
Identification: RA-COL-201		
Function: To accumulate the reflux of COL-201		
Operation: Continuous		
Design Data:		
	Type	
	Material	
	Diameter (ft)	8.4
	Length (ft)	17
	Capacity (ft^3)	931
	Residence Time (min)	5.0
	Operating Pressure (psig)	15.3
Total Bare Module Cost (USD)	144,148	

REFLUX ACCUMULATOR		
Identification: RA-COL-202		
Function: To accumulate the reflux of COL-202		
Operation: Continuous		
Design Data:		
	Type	
	Material	
	Diameter (ft)	5.4
	Length (ft)	11
	Capacity (ft^3)	252
	Residence Time (min)	5.0
	Operating Pressure (psig)	5.3
Total Bare Module Cost (USD)	80,634	

REFLUX ACCUMULATOR		
Identification: RA-COL-203		
Function: To accumulate the reflux of COL-203		
Operation: Continuous		
Design Data:		
	Type	
	Material	
	Diameter (ft)	3.8
	Length (ft)	7.6
	Capacity (ft^3)	86
	Residence Time (min)	5.0
	Operating Pressure (psig)	0
Total Bare Module Cost (USD)	56,709	

CONDENSER		
Identification: C-COL-201		
Function: To condense the overhead of COL-201		
Operation: Continuous		
Design Data:		
	Type	Shell & Tube
	Subtype	Fixed Head
	Material	Carbon Steel
	Length (ft)	20
	Area (ft^2)	2390
	Condenser Duty (BTU/hr)	4.50E+07
	Condenser Pressure (psia)	30
Total Bare Module Cost (USD)	85,901	

CONDENSER		
Identification: C-COL-202		
Function: To condense the overhead of COL-202		
Operation: Continuous		
Design Data:		
	Type	Shell & Tube
	Subtype	Fixed Head
	Material	Carbon Steel
	Length (ft)	20
	Area (ft^2)	467
	Condenser Duty (BTU/hr)	1.09E+08
	Condenser Pressure (psia)	20
Total Bare Module Cost (USD)	41,169	

CONDENSER		
Identification: C-COL-203		
Function: To condense the overhead of COL-203		
Operation: Continuous		
Design Data:		
	Type	Shell & Tube
	Subtype	Fixed Head
	Material	Carbon Steel
	Length (ft)	20
	Area (ft^2)	134
	Condenser Duty (BTU/hr)	3.64E+06
	Condenser Pressure (psia)	15
Total Bare Module Cost (USD)	33,453	

REBOILER		
Identification: R-COL-201		
Function: To vaporize the boilup of COL-201		
Operation: Continuous		
Design Data:		
	Type	Shell & Tube
	Subtype	Kettle Vaporizer
	Material	Carbon Steel
	Length	20
	$T_{hot, in}$	475
	$T_{hot, out}$	377
	Area (ft^2)	10,924
	Reboiler Duty (BTU/hr)	5.47E+07
	Temperature Change (F)	50
Total Bare Module Cost (USD)	346,020	

REBOILER		
Identification: R-COL-202		
Function: To vaporize the boilup of COL-202		
Operation: Continuous		
Design Data:		
	Type	Shell & Tube
	Subtype	Kettle Vaporizer
	Material	Carbon Steel
	Length	20
	$T_{hot, in}$	495
	$T_{hot, out}$	475
	Area (ft^2)	2,242
	Reboiler Duty (BTU/hr)	1.12E+07
	Temperature Change (F)	50
Total Bare Module Cost (USD)	161,052	

REBOILER		
Identification: R-COL-203		
Function: To vaporize the boilup of COL-203		
Operation: Continuous		
Design Data:		
	Type	Shell & Tube
	Subtype	Kettle Vaporizer
	Material	Carbon Steel
	Length	20
	$T_{hot,\ in}$	501
	$T_{hot,\ out}$	495
	Area (ft^2)	664
	Reboiler Duty (BTU/hr)	3.32E+06
	Temperature Change (F)	50
Total Bare Module Cost (USD)	103,397	

REACTOR		
Identification: R-101		
Function: To perform a dehydrocyclization reaction on S-111 to form aromatics, including BTX		
Operation: Continuous		
Material Handled		
	S-111	**S-112**
Mass Composition		
Benzene	0.006	0.062
Toluene	0.000	0.003
P-xylene	0.000	0.000
M-xylene	0.000	0.000
O-xylene	0.000	0.000
Methanol	0.000	0.000
Water	0.000	0.000
Methane	0.848	0.770
Nitrogen	0.021	0.021
Hydrogen	0.017	0.021
Carbon Monoxide	0.001	0.002
Carbon Dioxide	0.107	0.100
Naphthalene	0.000	0.020
Oxygen	0.000	0.000
Air	0.000	0.000
Coke	0.000	0.015
Total Flow Rate (lb/hr)	**2,400,000**	**2,400,000**
Design Data:		
Type	Fixed Bed with Catalyst	
Number of Reactors	3; one reacting, one on standby, one regenerating	
Reactor Casing	Ceramic Lining	
Catalyst Type	ZSM-5 Zeolite with Molybdenum Substrate	
Catalyst Mass (kg)	126424	
Catalyst Density (kg/m^3)	1400	
Temperature of Reaction (F)	1440	
Pressure of Reaction (psia)	43	
Diameter (ft)	15	
Length (ft)	30	
Volume (ft^3)	5314	
Pressure Drop (psia)	12.2	
Total Bare Module Cost (USD)	2,040,660	

REACTOR		
Identification: R-301		
Function: To perform an alkylation to form paraxylene from toluene		
Operation: Continuous		
Material Handled		
	S-303	**S-304**
Mass Composition		
Benzene	0.000	0.000
Toluene	0.703	0.454
P-xylene	0.001	0.287
M-xylene	0.000	0.000
O-xylene	0.000	0.000
Methanol	0.197	0.110
Water	0.100	0.148
Methane	0.000	0.000
Nitrogen	0.000	0.000
Hydrogen	0.000	0.000
Carbon Monoxide	0.000	0.000
Carbon Dioxide	0.000	0.000
Naphthalene	0.000	0.000
Oxygen	0.000	0.000
Air	0.000	0.000
Total Flow Rate (lb/hr)	**16,729**	**16,729**
Design Data:		
Type	Fluidized Bed with Catalyst	
Catalyst Type	ZSM-5 Zeolite with Molybdenum Substrate	
Catalyst Mass (kg)	6100	
Catalyst Density (kg/m^3)	1400	
Temperature of Reaction (F)	1104	
Pressure of Reaction (psia)	45	
Diameter (ft)	7	
Length (ft)	14	
Volume (ft^3)	513	
Pressure Drop (psia)	17	
Total Bare Module Cost (USD)	218,967	

HEAT EXCHANGER		
Identification: H-101/H-103		
Function: To cool stream S-112 from 1239 F to 250 F while heating stream S-109 from 160 F to 1172 F		
Operation: Continuous		
Material Handled		
	Hot Stream S-112	**Cold Stream S-109**
Mass Composition		
Benzene	0.062	0.006
Toluene	0.003	0.000
P-xylene	0.000	0.000
M-xylene	0.000	0.000
O-xylene	0.000	0.000
Methanol	0.000	0.000
Water	0.000	0.000
Methane	0.770	0.848
Nitrogen	0.021	0.021
Hydrogen	0.021	0.017
Carbon Monoxide	0.002	0.001
Carbon Dioxide	0.100	0.107
Naphthalene	0.020	0.000
Oxygen	0.000	0.000
Air	0.000	0.000
Total Flow Rate (lb/hr)	**2,400,000**	**2,400,000**
Design Data:		
Type	Shell & Tube	
Subtype	Kettle Vaporizer	
Material	Carbon Steel	
Duty (BTU/hr)	1.90E+09	
Heat Transfer Area (ft^2)	11607	
Length (ft)	20	
U (BTU/ft^3-hr-F)	150	
Number of HX	14	
Hot Side, T_{in} (F)	1239	
Hot Side, T_{out} (F)	250	
Cold Side, T_{in} (F)	160	
Cold Side, T_{out} (F)	1172	
Total Bare Module Cost (USD)	3,550,000	

HEAT EXCHANGER		
Identification: H-102/H-401		
Function: To cool stream S-407 from 2450 F to 1459 F while heating stream S-110 from 1172 F to 1440 F		
Operation: Continuous		
Material Handled		
	Hot Stream S-407	**Cold Stream S-110**
Mass Composition		
Benzene	0.000	0.006
Toluene	0.000	0.000
P-xylene	0.000	0.000
M-xylene	0.000	0.000
O-xylene	0.000	0.000
Methanol	0.000	0.000
Water	0.070	0.000
Methane	0.003	0.848
Nitrogen	0.739	0.021
Hydrogen	0.000	0.017
Carbon Monoxide	0.000	0.001
Carbon Dioxide	0.081	0.107
Naphthalene	0.000	0.000
Oxygen	0.106	0.000
Air	0.000	0.000
Total Flow Rate (lb/hr)	**2,097,800**	**2,400,000**
Design Data:		
Type	Shell & Tube	
Subtype	Kettle Vaporizer	
Material	Carbon Steel	
Duty (BTU/hr)	6.57E+08	
Heat Transfer Area (ft^2)	7,621	
Length (ft)	20	
U (BTU/ft^3-hr-F)	150	
Hot Side, T_{in} (F)	2450	
Hot Side, T_{out} (F)	1459	
Cold Side, T_{in} (F)	1172	
Cold Side, T_{out} (F)	1440	
Total Bare Module Cost (USD)	295,083	

HEAT EXCHANGER		
Identification: H-104/H-107		
Function: To cool stream S-120 from 472 F to 463 F while heating stream S-124 from -32 F to 170 F		
Operation: Continuous		
Material Handled		
	Hot Stream S-120	**Cold Stream S-124**
Mass Composition		
Benzene	0.062	0.696
Toluene	0.003	0.041
P-xylene	0.000	0.000
M-xylene	0.000	0.000
O-xylene	0.000	0.000
Methanol	0.000	0.000
Water	0.000	0.000
Methane	0.770	0.001
Nitrogen	0.021	0.000
Hydrogen	0.021	0.000
Carbon Monoxide	0.002	0.000
Carbon Dioxide	0.100	0.002
Naphthalene	0.020	0.259
Oxygen	0.000	0.000
Air	0.000	0.000
Total Flow Rate (lb/hr)	**2,400,000**	**192,156**
Design Data:		
Type	Shell & Tube	
Subtype	Kettle Vaporizer	
Material	Carbon Steel	
Duty (BTU/hr)	1.53E+07	
Heat Transfer Area (ft^2)	315	
Length (ft)	20	
U (BTU/ft^3-hr-F)	150	
Hot Side, T_{in} (F)	472	
Hot Side, T_{out} (F)	463	
Cold Side, T_{in} (F)	-32	
Cold Side, T_{out} (F)	170	
Total Bare Module Cost (USD)	68,889	

HEAT EXCHANGER		
Identification: H-301/H-302		
Function: To cool stream S-304 from 1231 F to 178 F while heating stream S-302 from 142 F to 1105 F		
Operation: Continuous		
Material Handled		
	Hot Stream S-304	**Cold Stream S-302**
Mass Composition		
Benzene	0.000	0.000
Toluene	0.454	0.703
P-xylene	0.287	0.001
M-xylene	0.000	0.000
O-xylene	0.000	0.000
Methanol	0.110	0.197
Water	0.148	0.100
Methane	0.000	0.000
Nitrogen	0.000	0.000
Hydrogen	0.000	0.000
Carbon Monoxide	0.000	0.000
Carbon Dioxide	0.000	0.000
Naphthalene	0.000	0.000
Oxygen	0.000	0.000
Air	0.000	0.000
Total Flow Rate (lb/hr)	**16,729**	**16,729**
Design Data:		
Type	Shell & Tube	
Subtype	Kettle Vaporizer	
Material	Carbon Steel	
Duty (BTU/hr)	1.24E+07	
Heat Transfer Area (ft^2)	1744	
Length (ft)	20	
U (BTU/ft^3-hr-F)	150	
Hot Side, T_{in} (F)	1229	
Hot Side, T_{out} (F)	178	
Cold Side, T_{in} (F)	141	
Cold Side, T_{out} (F)	1105	
Total Bare Module Cost (USD)	120,685	

HEAT EXCHANGER		
Identification: H-105		
Function: To cool stream S-121 from 463 F to 110 F		
Operation: Continuous		
Material Handled		
	Hot Stream S-121	**Cooling Water**
Mass Composition		
Benzene	0.062	0.000
Toluene	0.003	0.000
P-xylene	0.000	0.000
M-xylene	0.000	0.000
O-xylene	0.000	0.000
Methanol	0.000	0.000
Water	0.000	1.000
Methane	0.770	0.000
Nitrogen	0.021	0.000
Hydrogen	0.021	0.000
Carbon Monoxide	0.002	0.000
Carbon Dioxide	0.100	0.000
Naphthalene	0.020	0.000
Oxygen	0.000	0.000
Air	0.000	0.000
Total Flow Rate (lb/hr)	**2,400,000**	
Design Data:		
Type	Shell & Tube	
Subtype	Kettle Vaporizer	
Material	Carbon Steel	
Duty (BTU/hr)	5.31E+08	
Heat Transfer Area (ft^2)	9,854	
Length (ft)	20	
U (BTU/ft^3-hr-F)	150	
Number of HX	3	
Hot Side, T_{in} (F)	463	
Hot Side, T_{out} (F)	110	
Cold Side, T_{in} (F)	86	
Cold Side, T_{out} (F)	106	
Total Bare Module Cost (USD)	1,053,544	

HEAT EXCHANGER		
Identification: H-201		
Function: To cool stream S-213 from 278 F to 110 F		
Operation: Continuous		
Material Handled		
	Hot Stream S-213	**Cooling Water**
Mass Composition		
Benzene	0.000	0.000
Toluene	0.052	0.000
P-xylene	0.924	0.000
M-xylene	0.012	0.000
O-xylene	0.012	0.000
Methanol	0.000	0.000
Water	0.000	1.000
Methane	0.000	0.000
Nitrogen	0.000	0.000
Hydrogen	0.000	0.000
Carbon Monoxide	0.000	0.000
Carbon Dioxide	0.000	0.000
Naphthalene	0.001	0.000
Oxygen	0.000	0.000
Air	0.000	0.000
Total Flow Rate (lb/hr)	**5,120**	
Design Data:		
Type	Shell & Tube	
Subtype	Kettle Vaporizer	
Material	Carbon Steel	
Duty (BTU/hr)	3.28E+05	
Heat Transfer Area (ft^2)	150	
Length (ft)	20	
U (BTU/ft^3-hr-F)	100	
Hot Side, T_{in} (F)	278	
Hot Side, T_{out} (F)	110	
Cold Side, T_{in} (F)	86	
Cold Side, T_{out} (F)	106	
Total Bare Module Cost (USD)	64,975	

HEAT EXCHANGER		
Identification: H-202		
Function: To cool stream S-218 from 434 F to 110 F		
Operation: Continuous		
Material Handled		
	Hot Stream S-218	**Cooling Water**
Mass Composition		
Benzene	0.000	0.000
Toluene	0.000	0.000
P-xylene	0.002	0.000
M-xylene	0.000	0.000
O-xylene	0.000	0.000
Methanol	0.000	0.000
Water	0.000	1.000
Methane	0.000	0.000
Nitrogen	0.000	0.000
Hydrogen	0.000	0.000
Carbon Monoxide	0.000	0.000
Carbon Dioxide	0.000	0.000
Naphthalene	0.997	0.000
Oxygen	0.000	0.000
Air	0.000	0.000
Total Flow Rate (lb/hr)	**49,892**	
Design Data:		
Type	Shell & Tube	
Subtype	Kettle Vaporizer	
Material	Carbon Steel	
Duty (BTU/hr)	6.89E+06	
Heat Transfer Area (ft^2)	403	
Length (ft)	20	
U (BTU/ft^3-hr-F)	150	
Hot Side, T_{in} (F)	434	
Hot Side, T_{out} (F)	110	
Cold Side, T_{in} (F)	86	
Cold Side, T_{out} (F)	106	
Total Bare Module Cost (USD)	73,209	

HEAT EXCHANGER		
Identification: H-303		
Function: To cool stream S-305 from 178 F to 117 F		
Operation: Continuous		
Material Handled		
	Hot Stream S-305	**Cooling Water**
Mass Composition		
Benzene	0.000	0.000
Toluene	0.454	0.000
P-xylene	0.287	0.000
M-xylene	0.000	0.000
O-xylene	0.000	0.000
Methanol	0.110	0.000
Water	0.148	1.000
Methane	0.000	0.000
Nitrogen	0.000	0.000
Hydrogen	0.000	0.000
Carbon Monoxide	0.000	0.000
Carbon Dioxide	0.000	0.000
Naphthalene	0.000	0.000
Oxygen	0.000	0.000
Air	0.000	0.000
Total Flow Rate (lb/hr)	**16,729**	
Design Data:		
Type	Shell & Tube	
Subtype	Kettle Vaporizer	
Material	Carbon Steel	
Duty (BTU/hr)	1.55E+06	
Heat Transfer Area (ft^2)	336	
Length (ft)	20	
U (BTU/ft^3-hr-F)	150	
Hot Side, T_{in} (F)	178	
Hot Side, T_{out} (F)	117	
Cold Side, T_{in} (F)	86	
Cold Side, T_{out} (F)	106	
Total Bare Module Cost (USD)	70,671	

HEAT EXCHANGER		
Identification: H-402/H-408		
Function: To cool stream S-408 from 1459 F to 1384 F while heating stream S-401 from -32 F to 200 F		
Operation: Continuous		
Material Handled		
	Hot Stream S-408	**Cold Stream S-401**
Mass Composition		
Benzene	0.000	0.008
Toluene	0.000	0.000
P-xylene	0.000	0.000
M-xylene	0.000	0.000
O-xylene	0.000	0.000
Methanol	0.000	0.000
Water	0.070	0.000
Methane	0.003	0.836
Nitrogen	0.739	0.023
Hydrogen	0.000	0.023
Carbon Monoxide	0.000	0.002
Carbon Dioxide	0.081	0.109
Naphthalene	0.000	0.000
Oxygen	0.106	0.000
Air	0.000	0.000
Total Flow Rate (lb/hr)	**2,097,800**	**368,978**
Design Data:		
Type	Shell & Tube	
Subtype	Kettle Vaporizer	
Material	Carbon Steel	
Duty (BTU/hr)	4.78E+07	
Heat Transfer Area (ft^2)	358	
Length (ft)	20	
U (BTU/ft^3-hr-F)	100	
Hot Side, T_{in} (F)	1459	
Hot Side, T_{out} (F)	1384	
Cold Side, T_{in} (F)	-32	
Cold Side, T_{out} (F)	200	
Total Bare Module Cost (USD)	71,491	

HEAT EXCHANGER		
Identification: H-403		
Function: To cool stream S-409 from 1384 F to 501 F while heating S-411 from 106 F to 543 F		
Operation: Continuous		
Material Handled		
	Hot Stream S-409	**Cold Stream S-411**
Mass Composition		
Benzene	0.000	0.000
Toluene	0.000	0.000
P-xylene	0.000	0.000
M-xylene	0.000	0.000
O-xylene	0.000	0.000
Methanol	0.000	0.000
Water	0.070	1.000
Methane	0.003	0.000
Nitrogen	0.739	0.000
Hydrogen	0.000	0.000
Carbon Monoxide	0.000	0.000
Carbon Dioxide	0.081	0.000
Naphthalene	0.000	0.000
Oxygen	0.106	0.000
Air	0.000	0.000
Total Flow Rate (lb/hr)	**2,097,800**	**414,351**
Design Data:		
Type	Boiler	
Material	Carbon Steel	
Duty (BTU/hr)	1.55E+06	
Steam Produced (MMBTU/hr)	2.3	
Hot Side, T_{in} (F)	1384	
Hot Side, T_{out} (F)	501	
Cold Side, T_{in} (F)	106	
Cold Side, T_{out} (F)	543	
Total Bare Module Cost (USD)	2,290,000	

HEAT EXCHANGER		
Identification: H-407/H-203		
Function: To heat paraxylene product in S-216 from -13 F to 100 F		
Operation: Continuous		
Material Handled		
	Hot Stream S-419	**Cold Stream S-216**
Mass Composition		
Benzene	0.000	0.000
Toluene	0.000	0.000
P-xylene	0.000	0.998
M-xylene	0.000	0.000
O-xylene	0.000	0.002
Methanol	0.000	0.000
Water	1.000	0.000
Methane	0.000	0.000
Nitrogen	0.000	0.000
Hydrogen	0.000	0.000
Carbon Monoxide	0.000	0.000
Carbon Dioxide	0.000	0.000
Naphthalene	0.000	0.000
Oxygen	0.000	0.000
Air	0.000	0.000
Total Flow Rate (lb/hr)	**414,351**	**4,149**
Design Data:		
Type	Shell & Tube	
Subtype	Kettle Vaporizer	
Material	Carbon Steel	
Duty (BTU/hr)	6.57E+08	
Heat Transfer Area (ft^2)	150	
Length (ft)	20	
U (BTU/ft^3-hr-F)	50	
Number of HX	1	
Hot Side, T_{in} (F)	217	
Hot Side, T_{out} (F)	188	
Cold Side, T_{in} (F)	-13	
Cold Side, T_{out} (F)	100	
Total Bare Module Cost (USD)	64,975	

FURNACE			
Identification: F-401			
Function: To combust S-404 and S-406			
Operation: Continuous			
Material Handled			
	S-404	**S-406**	**S-407**
Mass Composition			
Benzene	0.008	0.000	0.000
Toluene	0.000	0.000	0.000
P-xylene	0.000	0.000	0.000
M-xylene	0.000	0.000	0.000
O-xylene	0.000	0.000	0.000
Methanol	0.000	0.000	0.000
Water	0.000	0.000	0.070
Methane	0.836	0.000	0.003
Nitrogen	0.023	0.767	0.739
Hydrogen	0.023	0.000	0.000
Carbon Monoxide	0.002	0.000	0.000
Carbon Dioxide	0.109	0.000	0.081
Naphthalene	0.000	0.000	0.000
Oxygen	0.000	0.233	0.106
Air	0.000	0.000	0.000
Total Flow Rate (lb/hr)	**78,268**	**2,019,530**	**2,097,800**
Design Data:			
	Material	Carbon Steel	
	Lining	Ceramic Lining	
	Heat Duty (BTU/hr)	1.65E+08	
	Flow Rate (lb/hr)	2,097,800	
Total Bare Module Cost (USD)	1,815,800		

CRYSTALLIZER			
Identification: CRY-201			
Function: To purify S-215 in to a high purity paraxylene product			
Operation: Continuous			
Material Handled			
	S-215	**S-216**	**S-217**
Mass Composition			
Benzene	0.000	0.000	0.000
Toluene	0.052	0.000	0.272
P-xylene	0.924	0.998	0.609
M-xylene	0.012	0.000	0.063
O-xylene	0.012	0.002	0.053
Methanol	0.000	0.000	0.000
Water	0.000	0.000	0.000
Methane	0.000	0.000	0.000
Nitrogen	0.000	0.000	0.000
Hydrogen	0.000	0.000	0.000
Carbon Monoxide	0.000	0.000	0.000
Carbon Dioxide	0.000	0.000	0.000
Naphthalene	0.001	0.000	0.003
Oxygen	0.000	0.000	0.000
Air	0.000	0.000	0.000
Total Flow Rate (lb/hr)	**5,120**	**4,149**	**971**
Design Data:			
	Type	Continuous cooling with jacket-scraped wall	
	Length (ft)	185	
	Number of Crystallizers	7	
	Heat Duty (BTU/hr)	25	
Total Bare Module Cost (USD)	7,843,949		

COST SUMMARIES AND ECONOMIC ANALYSES

Equipment Cost Summary

ID Name	Description	Cost	Price Source
Compressors			
C-101	Centrifugal Compressor	$17,805,769	Seider Correlation
C-102	Centrifugal Compressor	$17,805,769	Seider Correlation
C-103	Centrifugal Compressor	$17,805,769	Seider Correlation
C-104	Centrifugal Compressor	$25,137,732	Seider Correlation
C-105	Centrifugal Compressor	$25,137,732	Seider Correlation
C-106	Centrifugal Compressor	$25,137,732	Seider Correlation
C-401	Centrifugal Compressor	$1,182,205	Seider Correlation
C-402	Centrifugal Compressor	$25,321,584	Seider Correlation
Total		**$155,334,295**	
Turbines			
T-401	Turbine Generator	$1,231,946	Seider Correlation
T-402	Turbine Generator	$1,231,946	Seider Correlation
T-403	Turbine Generator	$1,231,946	Seider Correlation
Total		**$3,695,838**	
Columns			
COL-101	Flash Vessel	$1,119,992	Seider Correlation
COL-201	Distillation Column	$2,465,612	Seider Correlation
COL-202	Distillation Column	$1,076,046	Seider Correlation
COL-203	Distillation Column	$544,384	Seider Correlation
Total		**$5,206,034**	
Decanters			
D-301	Decanter	$89,273	Seider Correlation
	Total	**$89,273**	
Crystallizers			
CRY-201	Crystallizer	$7,843,949	Seider Correlation
Total		**$7,843,949**	
Pumps			
P-201	Centrifugal Pump	$15,679	Seider Correlation
P-202	Centrifugal Pump	$11,399	Seider Correlation
P-203	Centrifugal Pump	$11,309	Seider Correlation
P-204	Centrifugal Pump	$11,724	Seider Correlation
P-301	Centrifugal Pump	$10,868	Seider Correlation
P-302	Centrifugal Pump	$10,879	Seider Correlation
P-401	Centrifugal Pump	$44,817	Seider Correlation
Total		**$116,674**	

Heat Exchangers			
H-101/H-103	Shell and Tube Exchanger	$3,550,000	Vrana
H-102/H-401	Shell and Tube Exchanger	$295,083	Seider Correlation
H-104/H-107	Shell and Tube Exchanger	$69,889	Seider Correlation
H-105	Shell and Tube Exchanger	$1,053,544	Seider Correlation
H-106	Propane Refrigeration	$30,600,000	Bruce M. Vrana
H-201	Shell and Tube Exchanger	$64,975	Seider Correlation
H-202	Shell and Tube Exchanger	$73,210	Seider Correlation
H-203/H-407	Shell and Tube Exchanger	$64,975	Seider Correlation
H-301/H-302	Shell and Tube Exchanger	$120,685	Seider Correlation
H-303	Shell and Tube Exchanger	$70,671	Seider Correlation
H-402/H-408	Coil Tubing	$71,491	Seider Correlation
H-403	Boiler	$2,290,000	Bruce M. Vrana
F-401	Furnace	$1,815,000	L. Fabiano
Total		**$40,139,523**	
Reactors			
R-101	Fixed Bed	$2,040,660	Seider Correlation
R-301	Fluidized Bed	$218,967	Seider Correlation
Total		**$2,259,627**	
Storage Tanks			
SV-201	B Storage 1.5MM Gal	$1,042,000	Bruce M. Vrana
SV-202	PX Storage 1.5MM Gal	$521,000	Bruce M. Vrana
SV-203	N Storage 1.5MM Gal	$521,000	Bruce M. Vrana
Total		**$2,084,000**	

Total Bare Module Costs	**$228,330,885**
Total Fixed Cost per lb of Product per hr	**$1,660**

Fixed Capital Investment Summary

A rigorous cash flow analysis was generated with help from Brian K. Downey [2]. The total permanent investment of the plant is approximately $322MM with fixed costs of approximately $46.6MM. As shown in, maintenance accounts for 66% of the fixed costs. The fixed costs and fixed capital investment for the plant were estimated based on correlations from Seider et al. The cost of site preparations and the cost of service facilities were estimated at 5% of the total bare module equipment costs each. The cost of contingencies and contractor fees were estimated at 18% of the direct permanent investment and the cost of land and cost of plant startup were estimated at 2% and 10% of the total depreciable capita, respectively. Costs of wages and salaries were estimated based on 5 operators per shift: one each in process sections 1, 3, and 4 and two in section 2. A detailed line-item breakdown of the fixed costs and the permanent investment can be found in Figure 11 and Figure 12, respectively. The bare-module costs for each piece of equipment can be found in the Equipment Cost Summary above. Most of the equipment purchase and installation costs were estimated using correlations from Seider et al with a CE ration of 567/500 to account for 2015 prices. The remaining equipment purchase costs were estimated based on consultant recommendations. Email correspondence regarding these price estimates can be found in Appendix E.

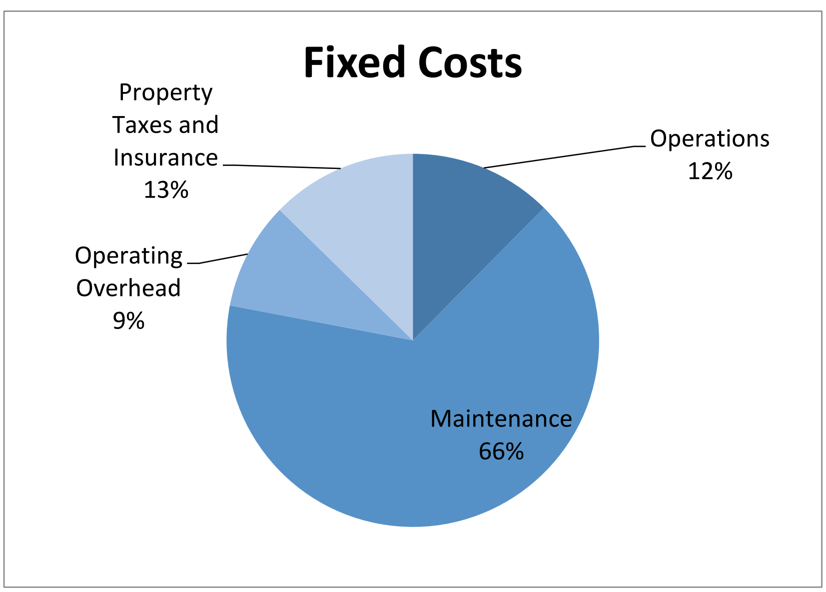

Figure 10: Fixed Cost Break Down

Fixed Cost Summary

Operations			
	Direct Wages and Benefits	$	2,080,000
	Direct Salaries and Benefits	$	312,000
	Operating Supplies and Services	$	124,800
	Technical Assistance to Manufacturing	$	1,500,000
	Control Laboratory	$	1,625,000
	Total Operations	**$**	**5,641,800**
Maintenance			
	Wages and Benefits	$	13,336,807
	Salaries and Benefits	$	3,334,202
	Materials and Services	$	13,336,807
	Maintenance Overhead	$	666,840
	Total Maintenance	**$**	**30,674,656**
Operating Overhead			
	General Plant Overhead:	$	1,353,474
	Mechanical Department Services:	$	457,512
	Employee Relations Department:	$	1,124,718
	Business Services:	$	1,410,663
	Total Operating Overhead	**$**	**4,346,366**
Property Taxes and Insurance			
	Property Taxes and Insurance:	$	5,927,470
Other Annual Expenses			
	Rental Fees (Office and Laboratory Space):	$	-
	Licensing Fees:	$	-
	Miscellaneous:	$	-
	Total Other Annual Expenses	**$**	**-**
Total Fixed Costs		**$**	**46,590,292**

Figure 11: Fixed Cost Summary [2]

Investment Summary		
Total Bare Module Costs:		
Fabricated Equipment	$ 55,460,276	
Process Machinery	$ 159,224,938	
Spares	$ -	
Storage	$ 2,084,000	
Other Equipment	$ -	
Catalysts	$ 4,817,363	
Computers, Software, Etc.	$ -	
Total Bare Module Costs:		**$ 221,586,577**
Direct Permanent Investment		
Cost of Site Preparations:	$ 11,079,329	
Cost of Service Facilities:	$ 11,079,329	
Allocated Costs for utility plants and related facilities:	$ -	
Direct Permanent Investment		**$ 243,745,235**
Total Depreciable Capital		
Cost of Contingencies & Contractor Fees	$ 43,874,142	
Total Depreciable Capital		**$ 287,619,377**
Total Permanent Investment		
Cost of Land:	$ 5,752,388	
Cost of Royalties:	$ -	
Cost of Plant Start-Up:	$ 28,761,938	
Total Permanent Investment - Unadjusted		$ 322,133,702
Site Factor		1.00
Total Permanent Investment		**$ 322,133,702**

Figure 12: Investment Summary [2]

Operating Cost – Cost of Manufacture

Variable costs were estimated to be $412MM annually when the plant is operating at 100% capacity. A chart showing the cost breakdown can be found in Figure 13 below. It shows that 66% of the variable costs come from raw materials of natural gas and methanol. A summary of the variable costs can be seen below in Figure 14. Prices and quantities for raw materials and utilities can be found in Figure 15. Prices of Benzene, paraxylene, and our natural gas feed were based on 2014 summer prices given to us by Bruce Vrana. The prices of naphthalene and methanol were based on prices from sources [10] and [13]. The prices of cooling water and electricity were taken from Seider et al [15].

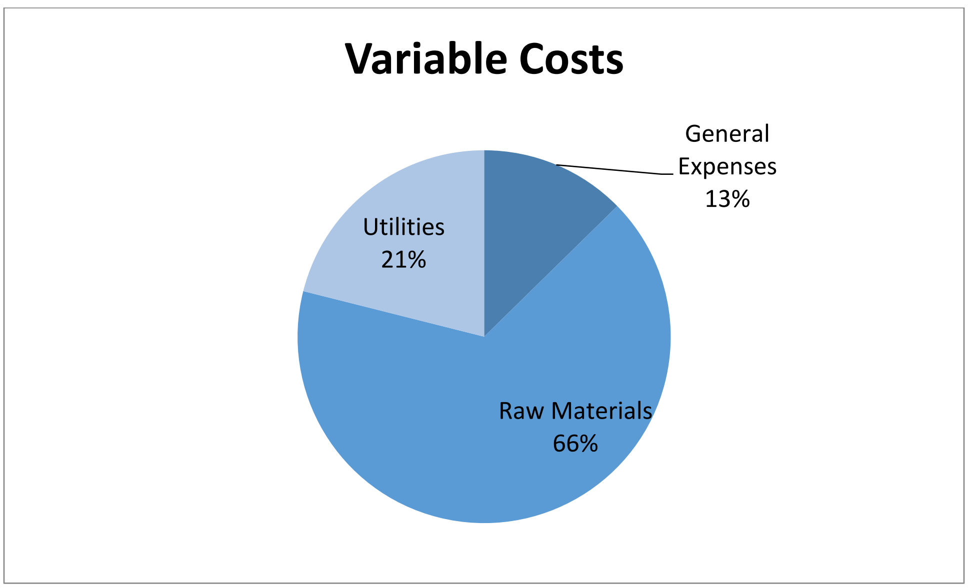

Figure 13: Variable Cost Summary

Variable Cost Summary

Variable Costs at 100% Capacity:

General Expenses

Selling / Transfer Expenses:		$	20,254,123
Direct Research:		$	32,406,597
Allocated Research:		$	3,375,687
Administrative Expense:		$	13,502,749
Management Incentive Compensation:		$	8,439,218
Total General Expenses		$	77,978,374
Raw Materials	$0.375078 per lb of Benzene		$408,433,655
Byproducts	$0.187885 per lb of Benzene		($204,594,290)
Utilities	$0.119245 per lb of Benzene		$129,849,446
Total Variable Costs		**$**	**411,667,185**

Figure 14: Annual Variable Cost Summary [2]

Raw Materials

	Raw Material:	Unit:	Required Ratio:	Cost of Raw Material:
1	Natural Gas	lb	4.6499331 lb per lb of Benzene	$0.080 per lb
2	Methanol	lb	0.0163114 lb per lb of Benzene	$0.19 per lb
	Total Weighted Average:			$0.375 per lb of Benzene

Byproducts

	Byproduct:	Unit:	Ratio to Product	Byproduct Selling Price
1	Para-xylene	lb	0.0301737 lb per lb of Benzene	$0.700 per lb
2	Napthalene	lb	0.3628269 lb per lb of Benzene	$0.400 per lb
3	CH4 / H2 Purge	Btu	5408.2672 Btu per lb of Benzene	$4.000E-06 per Btu
	Total Weighted Average:			$0.188 per lb of Benzene

Utilities

	Utility:	Unit:	Required Ratio	Utility Cost
1	High Pressure Steam	lb	0 lb per lb of Benzene	$0.000E+00 per lb
2	Low Pressure Steam	lb	0 lb per lb of Benzene	$0.000E+00 per lb
3	Process Water	gal	0 gal per lb of Benzene	$0.000E+00 per gal
4	Cooling Water	gal	23.780435 gal per lb of Benzene	$7.500E-05 per gal
5	Electricity	kWh	1.9576885 kWh per lb of Benzene	$0.060 per kWh

Figure 15: Detailed Variable Cost Inputs [2]

Profitability Analysis – Business Case

The profitability of the process can be determined by using a rigorous cash flow analysis to determine the net present value (NPV) of the project as well as the return on investment (ROI) and the internal rate of return. The cash flow analysis can be seen below in Figure 17. The project was determined to have a 2015 NPV of $285MM with an IRR of 31% and an ROI of 28.4% after the third year. The cash flow analysis used a 5-year depreciation schedule following the modified accelerated cost recovery system (MACRS) depreciation schedule as specified by the Internal Revenue Service (IRS). Based on these profitability measures, we recommend that further research is put into the process in order to more accurately determine its economic feasibility. Many assumptions and estimations were made when designing the process which must be explored in a more rigorous manner.

Sensitivity analysis was conducted to determine the project's sensitivity to a variety of changes. It was found that the project was most sensitive to a change in product (benzene) price, followed by total permanent investment, variable costs, and then fixed costs. The project's high sensitivity to both product prices as well as variable costs suggests that the project is highly dependent on macroeconomic market forces. Variable costs are determined primarily from prices of raw material inputs (i.e. natural gas, methanol) as well as byproduct prices (i.e. paraxylene, naphthalene). Variable costs could also be affected by change in process design; however these process design changes would likely have a far larger effect on the fixed costs of the project. Due to the recent uncertainty in oil prices, which have a significant correlation with the prices of petrochemicals such as benzene and paraxylene, a rigorous market and industry analysis must be conducted and a long-term view on prices must be established before the project could move forward.

Assuming 100% capacity utilization rate, the process would require the plant to capture 8% of the benzene market, by revenue. This could prove difficult as the market is fairly established with large petrochemical companies that produce similar quantities of benzene. Additionally, many of the major end users of benzene have vertically integrated and also produce their own benzene in-house. It may prove difficult to secure a contract to sell benzene in the quantities outlined in this project.

Profitability Measures

The Internal Rate of Return (IRR) for this project is 30.92%

The Net Present Value (NPV) of this project in 2015 is $ 284,776,100

ROI Analysis (Third Production Year)

Annual Sales	607,623,695
Annual Costs	(417,090,758)
Depreciation	(26,555,065)
Income Tax	(60,671,813)
Net Earnings	103,306,059
Total Capital Investment	363,786,568
ROI	28.40%

Figure 16: Profitability Analysis [2]

Cash Flow Summary

Year	Percentage of Design Capacity	Product Unit Price	Sales	Capital Costs	Working Capital	Var Costs	Fixed Costs	Depreciation	Taxible Income	Taxes	Net Earnings	Cash Flow	Cumulative Net Present Value at 15%
2015	0%		-	-	-	-	-	-	-	-	-	-	-
2016	0%		-	(331,938,300)	(15,924,100)	-	-	-	-	-	-	(347,862,400)	(302,489,100)
2017	45%	$0.62	303,811,800	-	(7,962,100)	(185,250,200)	(46,590,300)	(59,274,700)	12,696,600	(4,697,800)	7,998,900	59,311,500	(257,641,100)
2018	68%	$0.62	455,717,800	-	(7,962,100)	(277,875,300)	(46,590,300)	(94,839,500)	36,412,600	(13,472,700)	22,939,900	109,817,400	(185,434,300)
2019	90%	$0.62	607,623,700	-	-	(370,500,500)	(46,590,300)	(56,903,700)	133,629,200	(49,442,800)	84,186,400	141,090,100	(104,765,600)
2020	90%	$0.62	607,623,700	-	-	(370,500,500)	(46,590,300)	(34,142,200)	156,390,700	(57,864,600)	98,526,100	132,668,400	(38,806,000)
2021	90%	$0.62	607,623,700	-	-	(370,500,500)	(46,590,300)	(34,142,200)	156,390,700	(57,864,600)	98,526,100	132,668,400	18,550,200
2022	90%	$0.62	607,623,700	-	-	(370,500,500)	(46,590,300)	(17,071,100)	173,461,800	(64,180,900)	109,280,900	126,352,100	66,050,600
2023	90%	$0.62	607,623,700	-	-	(370,500,500)	(46,590,300)	-	190,532,900	(70,497,200)	120,035,800	120,035,800	105,290,500
2024	90%	$0.62	607,623,700	-	-	(370,500,500)	(46,590,300)	-	190,532,900	(70,497,200)	120,035,800	120,035,800	139,412,200
2025	90%	$0.62	607,623,700	-	-	(370,500,500)	(46,590,300)	-	190,532,900	(70,497,200)	120,035,800	120,035,800	169,083,200
2026	90%	$0.62	607,623,700	-	-	(370,500,500)	(46,590,300)	-	190,532,900	(70,497,200)	120,035,800	120,035,800	194,884,100
2027	90%	$0.62	607,623,700	-	-	(370,500,500)	(46,590,300)	-	190,532,900	(70,497,200)	120,035,800	120,035,800	217,319,600
2028	90%	$0.62	607,623,700	-	-	(370,500,500)	(46,590,300)	-	190,532,900	(70,497,200)	120,035,800	120,035,800	236,828,800
2029	90%	$0.62	607,623,700	-	-	(370,500,500)	(46,590,300)	-	190,532,900	(70,497,200)	120,035,800	120,035,800	253,793,300
2030	90%	$0.62	607,623,700	-	-	(370,500,500)	(46,590,300)	-	190,532,900	(70,497,200)	120,035,800	120,035,800	268,545,000
2031	90%	$0.62	607,623,700	-	31,848,300	(370,500,500)	(46,590,300)	-	190,532,900	(70,497,200)	120,035,800	151,884,000	284,776,100

Figure 17: Summary of Process Cash Flows [2]

Product Price		Total Permanent Investment										
		$165,969,153	$199,162,984	$232,356,815	$265,550,645	$298,744,476	***$331,938,307***	$365,132,137	$398,325,968	$431,519,799	$464,713,629	$497,907,460
	$0.31	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR
	$0.37	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR
	$0.43	20.49%	11.98%	5.51%	0.22%	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR
	$0.50	50.74%	37.34%	27.91%	20.90%	15.43%	11.01%	7.32%	4.17%	1.41%	-1.05%	-3.28%
	$0.56	74.29%	56.24%	43.69%	34.51%	27.52%	22.00%	17.52%	13.78%	10.60%	7.84%	5.42%
	$0.62	94.96%	72.74%	57.29%	46.05%	37.55%	30.92%	25.59%	21.20%	17.52%	14.36%	11.63%
	$0.68	113.75%	87.77%	69.66%	56.48%	46.55%	38.82%	32.65%	27.61%	23.41%	19.85%	16.78%
	$0.74	131.12%	101.73%	81.16%	66.17%	54.87%	46.10%	39.11%	33.43%	28.72%	24.74%	21.33%
	$0.81	147.34%	114.84%	91.99%	75.29%	62.70%	52.93%	45.16%	38.85%	33.63%	29.25%	25.50%
	$0.87	162.58%	127.25%	102.27%	83.97%	70.14%	59.41%	50.89%	43.97%	38.26%	33.47%	29.40%
	$0.93	176.97%	139.06%	112.09%	92.27%	77.27%	65.62%	56.36%	48.86%	42.67%	37.49%	33.09%

Figure 18: Sensitivity Analysis on IRR of Total Permanent Investment vs. Product Price [2]

Product Price		$205,833,592	$247,000,311	$288,167,029	$329,333,748	$370,500,466	***$411,667,185***	$452,833,903	$494,000,622	$535,167,340	$576,334,058	$617,500,777
	$0.31	12.25%	2.66%	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR
	$0.37	23.38%	16.83%	9.02%	-2.16%	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR
	$0.43	32.43%	26.87%	20.83%	13.99%	5.50%	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR
	$0.50	40.46%	35.41%	30.11%	24.45%	18.23%	11.01%	1.56%	Negative IRR	Negative IRR	Negative IRR	Negative IRR
	$0.56	47.85%	43.14%	38.26%	33.17%	27.79%	22.00%	15.54%	7.84%	-3.10%	Negative IRR	Negative IRR
	$0.62	54.80%	50.31%	45.71%	40.97%	36.06%	30.92%	25.45%	19.51%	12.76%	4.40%	Negative IRR
	$0.68	61.39%	57.08%	52.69%	48.20%	43.58%	38.82%	33.87%	28.66%	23.09%	16.96%	9.85%
	$0.74	67.70%	63.54%	59.30%	54.99%	50.60%	46.10%	41.47%	36.68%	31.68%	26.39%	20.70%
	$0.81	73.78%	69.73%	65.63%	61.46%	57.23%	52.93%	48.52%	44.01%	39.36%	34.54%	29.48%
	$0.87	79.64%	75.70%	71.70%	67.66%	63.57%	59.41%	55.19%	50.87%	46.47%	41.94%	37.26%
	$0.93	85.33%	81.47%	77.57%	73.64%	69.65%	65.62%	61.53%	57.38%	53.15%	48.84%	44.42%

Figure 19: Sensitivity Analysis on IRR of Total Permanent Investment vs. Product Price [2]

Product Price	Fixed Costs: $23,295,146	$27,954,175	$32,613,204	$37,272,233	$41,931,263	***$46,590,292***	$51,249,321	$55,908,350	$60,567,379	$65,226,408	$69,885,438
$0.31	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR
$0.37	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR
$0.43	1.91%	0.23%	-1.59%	-3.61%	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR
$0.50	16.25%	15.24%	14.21%	13.17%	12.10%	11.01%	9.89%	8.74%	7.55%	6.33%	5.05%
$0.56	26.33%	25.48%	24.62%	23.75%	22.88%	22.00%	21.12%	20.23%	19.33%	18.42%	17.50%
$0.62	34.88%	34.09%	33.30%	32.51%	31.71%	30.92%	30.12%	29.32%	28.52%	27.71%	26.90%
$0.68	42.59%	41.84%	41.08%	40.33%	39.58%	38.82%	38.07%	37.31%	36.56%	35.80%	35.04%
$0.74	49.74%	49.01%	48.28%	47.55%	46.82%	46.10%	45.37%	44.64%	43.91%	43.19%	42.46%
$0.81	56.49%	55.77%	55.06%	54.35%	53.64%	52.93%	52.22%	51.51%	50.80%	50.09%	49.38%
$0.87	62.91%	62.21%	61.51%	60.81%	60.11%	59.41%	58.72%	58.02%	57.32%	56.63%	55.93%
$0.93	69.07%	68.38%	67.69%	67.00%	66.31%	65.62%	64.93%	64.25%	63.56%	62.88%	62.19%

Figure 20: Sensitivity Analysis on IRR of Total Permanent Investment vs. Product Price [2]

CONCLUSIONS AND OTHER CONSIDERATIONS

Other Considerations

There are several factors that warrant special attention in this process. The most essential consideration to the safety of the process involves the feed to F-101 in Section IV. It would save approximately $1MM to combine the purge stream, which is rich in CH_4, and the air feed stream to the furnace before compressing them. However, this setup would create a very flammable mixture under high pressure that poses a large safety threat. If this stream were exposed to any form of ignition source, the results would be catastrophic in a process of this size. It is essential to keep the purge stream and air streams separate until they enter the controlled environment of the furnace.

Another safety issue should be considered in regard to the benzene and paraxylene storage. These compounds are flammable and carcinogenic, so their storage tanks cannot be as simple as storing water. Due to the higher volatility of benzene, measures such as a nitrogen blanket may even be necessary in order to keep it in its liquid state. Even though this is not considered as part of this project, plant designers must take facts into consideration in order to preserve the safety of the plant employees.

Another thing to consider is that the catalyst for the dehydrocyclization reactor has only ever been used on a lab scale. In our design, we assumed that all of the values given in US '237 would scale to our requirements, but this is not likely to be the case since it is much easier to produce ideal conditions for the catalyst in a lab rather than a large-scale reactor. Further testing or research should be conducted to ensure that the conversion of CH4 remains high enough to produce a profitable process.

Finally, some consideration needs to be given to the amount of CO_2 that our process produces. Our process releases 673,000 tons of CO_2 per year into the atmosphere, or about the same amount as 142,000 cars [4]. This is a considerable amount by any measure, so measures should be taken to mitigate the amount of CO_2 released. While there is not currently a tax on CO_2 emissions, experts predict that there will be allowances of around \$20 per ton of CO_2 equivalent in the future. If this were the case, our emissions would cost us \$13.5MM per year. We recommend that management keep this in mind in the instillation of the plant, but no further measures must be taken at this time.

Conclusions and Recommendations

After analyzing the process outlined in this report, we have concluded that it is profitable given our positive NPV. The current process produces 1.3B lb/yr of BTX. Due to the large scale of the plant, capital investment is extremely high, totaling \$357 MM capital investment. However, with the large scale production of benzene and paraxylene, as well as the reduction of costs from efficient heat integration, our process was found to be very profitable. The plant had an ROI of 28.4% and NPV of \$285 MM.

Based on the sensitivity analysis, our project has the highest sensitivity to market prices, such as those of the product, raw materials, and byproducts. The project would have a negative NPV if the product (benzene) price dropped 16% (from \$0.62 to \$0.52/lb). Similarly, the NPV would be negative if the natural gas price increased 38% from \$0.08/lb to \$0.11/lb.

One recommendation to further reduce the cost of the plant would be to replace the propane refrigeration process (which totals \$30.6 million in capital investments). This could potentially be accomplished by inserting a multi-stage compressor in order to pressurize the reactor effluent before it reaches the flash vessel. This scheme was originally not chosen because it would not provide as effective of a separation.

Another potential recommendation would be to look at a catalyst that increases the conversion of methane from 12.4%. This would lead to a reduction in the purchase of natural gas feed, and allow for a lower flow rate through all the equipment, reducing both capital and variable costs considerably. Based on the economic analysis above, it is still recommended to pursue construction of the designed plant.

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APPENDICES

Appendix A: Sample Calculations

Appendix A.1: Sample Calculations for Heat Exchangers

To calculate the surface area required for a heat exchanger, Equation 1 can be used. Using ASPEN, we determined the duty for each exchanger, the inlet and outlet temperatures, and selected an appropriate heat transfer coefficient for each exchanger. After these values were known, the required surface area can be calculated according to Equation 1.

$$Q = UA\Delta T_{LM} = U * A * \frac{\left((T_{hi} - T_{co}) - (T_{ho} - T_{ci})\right)}{\ln\left(\frac{T_{hi} - T_{co}}{T_{ho} - T_{ci}}\right)} \qquad (Equation\ 1)$$

$where$:

$Q = duty\ of\ the\ exchanger\ \left(\frac{BTU}{hr}\right)$

$U = heat\ exchange\ transfer\ coefficient\ \left(\frac{BTU}{hr - ft{-}^{o}R}\right)$

$A = surface\ area\ of\ the\ exchanger\ (ft^2)$

$T_{hi} = inlet\ temperature\ of\ the\ hot\ stream\ (^{o}R)$

$T_{ho} = outlet\ temperature\ of\ the\ hot\ stream\ (^{o}R)$

$T_{ci} = inlet\ temperature\ of\ the\ cold\ stream\ (^{o}R)$

$T_{co} = outlet\ temperature\ of\ the\ cold\ stream\ (^{o}R)$

The parameters for H-201 from Equation 1 are as follows:

Q	6.89E+06	BTU/hr
T_{hi}	424	^{o}R
T_{ho}	110	^{o}R
T_{ci}	86	^{o}R
T_{co}	106	^{o}R
ΔT_{lm}	113.78	^{o}R
U	150	BTU/hr-ft^2-^{o}R
A	403.43	ft^2

Appendix 1.2: Sample Calculations for Pumps

To calculate the work required by a pump, Equation 3 should be used. This equation works for centrifugal pumps.

$$W = 7.27x10^{-5} * F * \Delta P \qquad (Equation\ 3)$$

$$\begin{aligned}
&where: \\
&W = work\ (hP) \\
&F = volumetric\ flowrate\ \left(\frac{ft^3}{hr}\right) \\
&\Delta P = pressure\ change\ (psia)
\end{aligned}$$

The parameters for P-201 according to Equation 3 are as follows:

F	3810	ft^3/hr
ΔP	50	psia
W	13.8	hP

Appendix A.3: Sample Calculations for Distillation Columns

For costing purposes, it is essential to calculate the diameter of any columns. To do this, several properties of the column and fluids must be known as shown below in Equations 4-7.

$$U_f = C_{SB}F_{ST}F_FF_{HA}\sqrt{\frac{\rho_L - \rho_V}{\rho_V}} \qquad (Equation\ 4)$$

$$C_{SB} = f(F_{LG,}, tray\ spacing)\ according\ to\ Figure\ 19.4\ in\ Seider\ et.al$$

$$F_{LG} = \frac{L}{V}\sqrt{\frac{\rho_V}{\rho_L}} \qquad (Equation\ 5)$$

$$V = (1 - \frac{A_D}{A_T}) * \frac{\pi D^2}{4} * f * U_f \qquad (Equation\ 6)$$

$$D = \sqrt{\frac{4V}{0.9D^2U}} \qquad (Equation\ 7)$$

$where$:

$U_f = flooding\ velocity\ \left(\frac{ft}{s}\right)$

$C_{SB} = parameter\ according\ to\ Figure\ 14.6$

$F_{ST} = surface\ tension\ factor = \left(\frac{\sigma}{20}\right)^{0.2}$

$\sigma = surface\ tension\ of\ liquid\ \left(\frac{dyne}{cm}\right)$

$F_F = foaming\ factor$

$F_{HA} = hole\ area\ factor$

$\rho_L = density\ of\ the\ liquid\ phase \left(\frac{lb}{ft^3}\right)$

$\rho_V = density\ of\ the\ liquid\ phase\ \left(\frac{lb}{ft^3}\right)$

$L = liquid\ volumetric\ flow\ rate\ \left(\frac{ft^3}{hr}\right)$

$V = vapor\ volumetric\ flow\ rate\ \left(\frac{ft^3}{hr}\right)$

$A_D = downcomer\ area\ (ft^2)$

$A_T = total\ tray\ area\ (ft^2)$

$D = diameter\ (ft)$

$f = fraction\ of\ flooding\ velocity$

The parameters for COL-201 according to Equations 4-7 are as follows:

C_{SB}	0.125	--
F_{ST}	1.02	--
F_F	1	--
F_{HA}	1	--
F_{LG}	0.039	--
ρ_L	51.39	lb/ft^3
ρ_V	0.34	lb/ft^3
σ	21.93	dyne/cm
f	0.85	--
U_f	1.57	ft/s
L	66764	ft^3/hr
V	137661	ft^3/hr
$(1-A_D/A_T)$	0.9	--
D	11.0	ft

Appendix A.4: Sample Calculations for Reactors

Reactor R-101 is a fixed bed catalytic reactor. The reactor specifications were designed according to patent US8278237. The reactor was run adiabatically, to determine the maximum temperature change that would occur, as the effluent to the reactor was used to heat the feed.

Required BTX Production: 10^9 lb/yr

Actual BTX Production: $1.27*10^9$ lb/yr

BTX Formation Rate: 0.002 mmol/s/g-cat → 10,045 lb/yr/kg-cat

Catalyst Required: $\frac{BTX\ Production\ Rate}{BTX\ Formation\ Rate} = \frac{1.27*10^9 \frac{lb}{yr}}{\frac{10{,}045\ lb}{yr\ kg-cat}}$ = 126,424 kg catalyst (Equation 8)

Density of Catalyst: 1400 kg/m^3

Reactor Volume = $\frac{Mass\ of\ Catalyst}{Density\ of\ Catalyst\ (1-\epsilon)}$ = 151 m^3 (Equation 9)

Length = 9.2 m

Diameter = 4.6 m

To Confirm Pressure Drop:

$$\Delta P = \frac{150\mu L\ (1-\epsilon)^2 Vs}{Dp\ \epsilon^3} + \frac{1.75\ L\ \rho\ (1-\epsilon) Vs^2}{Dp\ \epsilon^3} \quad \text{(Equation 10)}$$

Where:

$\Delta P = pressure\ drop\ across\ the\ reactor\ bed\ (kPa)$

$\mu = dynamic\ visocity\ \frac{kg}{m-s}$ = $3.22*10^{-5}$

$\epsilon = void\ fraction$ = 0.4

$V_s = superficial\ velocity\ \left(\frac{m}{s}\right)$ = 0.009

$\rho = density\ of\ fluid$ (kg/m^3) = 0.72

$L = length\ of\ the\ bed$ = 7.72

$D_p = spherical\ particle\ diameter$ = 0.005 m

Calculated Pressure Drop = 66 kPa =10 psia

Reactor R-201 is a fluidized bed catalytic reactor. The reactor specifications were designed according to patent U6642426. The reactor was run adiabatically, to determine the maximum temperature change that would occur, as the effluent to the reactor was used to heat the feed. The catalyst is considered to be in Group A of Geldart's Groupings for Catalysts in Fluidized Beds. Thus, the volume doubles during fluidized expansion. The results of this expansion are also confirmed by the Zaki-Richardson correlation.

Catalyst Required: $\frac{Mass\ Flow\ Rate}{WHSV}$ (Equation 11)

Reactor Volume = $\frac{Mass\ of\ Catalyst}{Density\ of\ Catalyst\ (1-\epsilon)}$ (Equation 12)

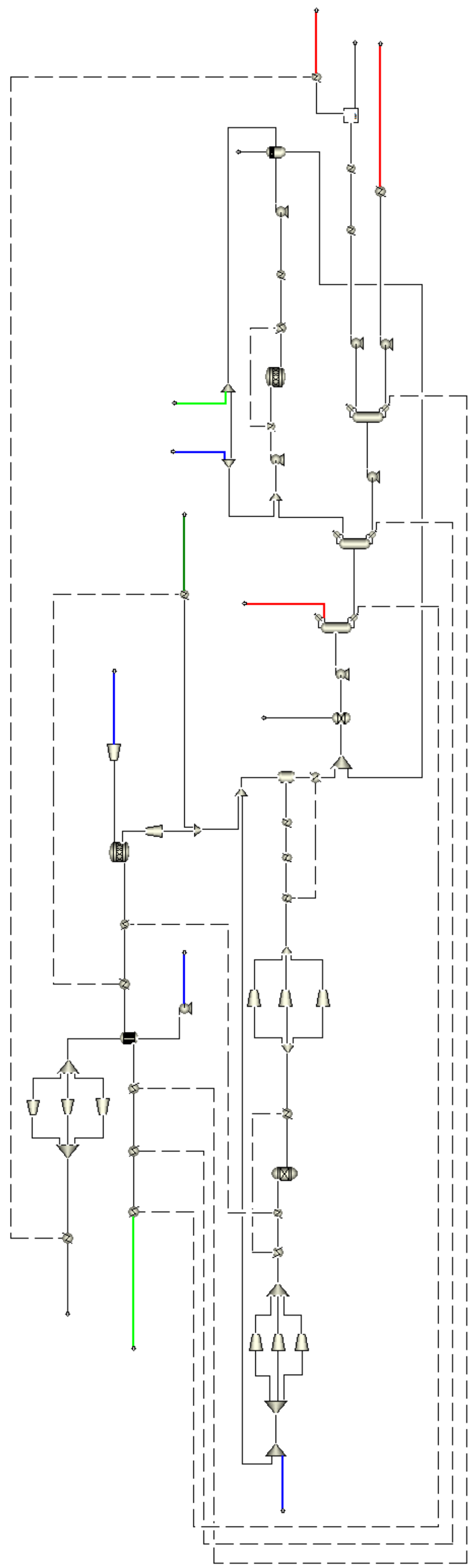
$Zaki - Richardson\ Correlation\colon \frac{Uo}{Ut} = \epsilon^{n}$ (Equation 13)

The parameters for R-201 according to the above Equations are as follows:

Mass Flow Rate	7320	kg/hr
WHSV	1.2	hr^{-1}
Catalyst Required	6100	kg
Catalyst Density	1400	kg/m^3
Reactor Volume	7.3	m^3
Volume with Expansion	14.5	m^3
Reactor Length	4.2	m
Reactor Diameter	2.1	m
n (For Equation 13)	2.4	For turbulent flow
Reactor Volume	14.5	m^3

Appendix B: ASPEN Results

Appendix B.1: ASPEN Flowsheet



Appendix B.2: Block Report

```
BLOCK:  C-101    MODEL: COMPR
 -----------------------------
   INLET STREAM:           S-103
   OUTLET STREAM:          S-104
   PROPERTY OPTION SET:    SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

                      ***  MASS AND ENERGY BALANCE  ***
                                   IN              OUT        RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(LBMOL/HR)           52149.9         52149.9         0.00000
       MASS(LB/HR   )           809463.         809463.        0.143818E-15
       ENTHALPY(BTU/HR  )     -0.174117E+10   -0.166703E+10   -0.425791E-01

                      ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E           0.172426E+08  LB/HR
    PRODUCT STREAMS CO2E        0.172426E+08  LB/HR
    NET STREAMS CO2E PRODUCTION   0.00000     LB/HR
    UTILITIES CO2E PRODUCTION     0.00000     LB/HR
    TOTAL CO2E PRODUCTION         0.00000     LB/HR

                           ***  INPUT DATA  ***

   ISENTROPIC COMPRESSOR USING ASME METHOD
    OUTLET PRESSURE  PSIA                                      91.0000
    ISENTROPIC EFFICIENCY                                       0.85000
    MECHANICAL EFFICIENCY                                       1.00000

                           ***  RESULTS  ***

    INDICATED  HORSEPOWER REQUIREMENT  HP               29,137.1
    BRAKE      HORSEPOWER REQUIREMENT  HP               29,137.1
    NET WORK REQUIRED                  HP               29,137.1
    POWER LOSSES                       HP                    0.0
    ISENTROPIC HORSEPOWER REQUIREMENT  HP               24,766.6
    CALCULATED OUTLET TEMP  F                              160.075
    ISENTROPIC TEMPERATURE  F                              135.756
    EFFICIENCY (POLYTR/ISENTR) USED                          0.85000
    OUTLET VAPOR FRACTION                                    1.00000
    HEAD DEVELOPED,       FT-LBF/LB                     60,580.7
    MECHANICAL EFFICIENCY USED                               1.00000
    INLET HEAT CAPACITY RATIO                                1.33902
    INLET VOLUMETRIC FLOW RATE , CUFT/HR             8,901,210.
    OUTLET VOLUMETRIC FLOW RATE, CUFT/HR             3,797,010.
    INLET  COMPRESSIBILITY FACTOR                            0.99511
    OUTLET COMPRESSIBILITY FACTOR                            0.99623
    AV. ISENT. VOL. EXPONENT                                 1.31995
    AV. ISENT. TEMP EXPONENT                                 1.31969
    AV. ACTUAL VOL. EXPONENT                                 1.38344
    AV. ACTUAL TEMP EXPONENT                                 1.38161

 BLOCK:  C-102    MODEL: COMPR
 -----------------------------
   INLET STREAM:           S-105
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  OUTLET STREAM:         S-106
  PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

                    ***  MASS AND ENERGY BALANCE  ***
                                   IN              OUT        RELATIVE DIFF.
   TOTAL BALANCE
      MOLE(LBMOL/HR)            52149.9         52149.9         0.00000
      MASS(LB/HR   )            809463.         809463.        0.143818E-15
      ENTHALPY(BTU/HR  )      -0.174117E+10   -0.166703E+10   -0.425791E-01

                    ***  CO2 EQUIVALENT SUMMARY ***
   FEED STREAMS CO2E            0.172426E+08  LB/HR
   PRODUCT STREAMS CO2E         0.172426E+08  LB/HR
   NET STREAMS CO2E PRODUCTION   0.00000      LB/HR
   UTILITIES CO2E PRODUCTION     0.00000      LB/HR
   TOTAL CO2E PRODUCTION         0.00000      LB/HR

                         ***  INPUT DATA  ***

  ISENTROPIC CENTRIFUGAL COMPRESSOR
   OUTLET PRESSURE  PSIA                                          91.0000
   ISENTROPIC EFFICIENCY                                           0.85000
   MECHANICAL EFFICIENCY                                           1.00000

                         ***  RESULTS  ***

   INDICATED  HORSEPOWER REQUIREMENT  HP                29,137.1
   BRAKE      HORSEPOWER REQUIREMENT  HP                29,137.1
   NET WORK REQUIRED                  HP                29,137.1
   POWER LOSSES                       HP                     0.0
   ISENTROPIC HORSEPOWER REQUIREMENT  HP                24,766.6
   CALCULATED OUTLET TEMP  F                               160.075
   ISENTROPIC TEMPERATURE  F                               135.756
   EFFICIENCY (POLYTR/ISENTR) USED                           0.85000
   OUTLET VAPOR FRACTION                                     1.00000
   HEAD DEVELOPED,       FT-LBF/LB                      60,580.7
   MECHANICAL EFFICIENCY USED                                1.00000
   INLET HEAT CAPACITY RATIO                                 1.33902
   INLET VOLUMETRIC FLOW RATE , CUFT/HR              8,901,210.
   OUTLET VOLUMETRIC FLOW RATE, CUFT/HR              3,797,010.
   INLET  COMPRESSIBILITY FACTOR                             0.99511
   OUTLET COMPRESSIBILITY FACTOR                             0.99623
   AV. ISENT. VOL. EXPONENT                                  1.31995
   AV. ISENT. TEMP EXPONENT                                  1.31969
   AV. ACTUAL VOL. EXPONENT                                  1.38344
   AV. ACTUAL TEMP EXPONENT                                  1.38161

BLOCK:  C-103    MODEL: COMPR
-----------------------------
  INLET STREAM:          S-107
  OUTLET STREAM:         S-108
  PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

                    ***  MASS AND ENERGY BALANCE  ***
                                   IN              OUT        RELATIVE DIFF.
   TOTAL BALANCE
      MOLE(LBMOL/HR)            52149.9         52149.9         0.00000
```

```
      MASS(LB/HR   )           809463.         809463.         0.00000
      ENTHALPY(BTU/HR  )      -0.174117E+10   -0.166703E+10   -0.425791E-01

                   ***  CO2 EQUIVALENT SUMMARY ***
   FEED STREAMS CO2E            0.172426E+08  LB/HR
   PRODUCT STREAMS CO2E         0.172426E+08  LB/HR
   NET STREAMS CO2E PRODUCTION   0.00000      LB/HR
   UTILITIES CO2E PRODUCTION     0.00000      LB/HR
   TOTAL CO2E PRODUCTION         0.00000      LB/HR

                        ***  INPUT DATA  ***

  ISENTROPIC CENTRIFUGAL COMPRESSOR
   OUTLET PRESSURE  PSIA                                      91.0000
   ISENTROPIC EFFICIENCY                                       0.85000
   MECHANICAL EFFICIENCY                                       1.00000

                        ***  RESULTS  ***

   INDICATED  HORSEPOWER REQUIREMENT  HP               29,137.1
   BRAKE      HORSEPOWER REQUIREMENT  HP               29,137.1
   NET WORK REQUIRED                  HP               29,137.1
   POWER LOSSES                       HP                    0.0
   ISENTROPIC HORSEPOWER REQUIREMENT  HP               24,766.6
   CALCULATED OUTLET TEMP  F                              160.075
   ISENTROPIC TEMPERATURE  F                              135.756
   EFFICIENCY (POLYTR/ISENTR) USED                          0.85000
   OUTLET VAPOR FRACTION                                    1.00000
   HEAD DEVELOPED,       FT-LBF/LB                     60,580.7
   MECHANICAL EFFICIENCY USED                               1.00000
   INLET HEAT CAPACITY RATIO                                1.33902
   INLET VOLUMETRIC FLOW RATE , CUFT/HR             8,901,210.
   OUTLET VOLUMETRIC FLOW RATE, CUFT/HR             3,797,010.
   INLET  COMPRESSIBILITY FACTOR                            0.99511
   OUTLET COMPRESSIBILITY FACTOR                            0.99623
   AV. ISENT. VOL. EXPONENT                                 1.31995
   AV. ISENT. TEMP EXPONENT                                 1.31969
   AV. ACTUAL VOL. EXPONENT                                 1.38344
   AV. ACTUAL TEMP EXPONENT                                 1.38161

BLOCK:  C-104    MODEL: COMPR
-----------------------------
  INLET STREAM:          S-114
  OUTLET STREAM:         S-115
  PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

                   ***  MASS AND ENERGY BALANCE  ***
                                IN              OUT        RELATIVE DIFF.
   TOTAL BALANCE
      MOLE(LBMOL/HR)           50506.6         50506.6         0.00000
      MASS(LB/HR   )           809455.         809455.         0.00000
      ENTHALPY(BTU/HR  )      -0.144805E+10   -0.133396E+10   -0.787881E-01

                   ***  CO2 EQUIVALENT SUMMARY ***
   FEED STREAMS CO2E            0.156539E+08  LB/HR
   PRODUCT STREAMS CO2E         0.156539E+08  LB/HR
   NET STREAMS CO2E PRODUCTION   0.00000      LB/HR
```

```
   UTILITIES CO2E PRODUCTION     0.00000      LB/HR
   TOTAL CO2E PRODUCTION         0.00000      LB/HR

                          ***  INPUT DATA  ***

  ISENTROPIC CENTRIFUGAL COMPRESSOR
   OUTLET PRESSURE  PSIA                                      90.0000
   ISENTROPIC EFFICIENCY                                       0.85000
   MECHANICAL EFFICIENCY                                       1.00000

                          ***  RESULTS  ***

   INDICATED  HORSEPOWER REQUIREMENT  HP                  44,838.7
   BRAKE      HORSEPOWER REQUIREMENT  HP                  44,838.7
   NET WORK REQUIRED                  HP                  44,838.7
   POWER LOSSES                       HP                       0.0
   ISENTROPIC HORSEPOWER REQUIREMENT  HP                  38,112.9
   CALCULATED OUTLET TEMP  F                                 471.192
   ISENTROPIC TEMPERATURE  F                                 440.155
   EFFICIENCY (POLYTR/ISENTR) USED                             0.85000
   OUTLET VAPOR FRACTION                                       1.00000
   HEAD DEVELOPED,       FT-LBF/LB                        93,227.5
   MECHANICAL EFFICIENCY USED                                  1.00000
   INLET HEAT CAPACITY RATIO                                   1.26736
   INLET VOLUMETRIC FLOW RATE , CUFT/HR                        0.142395+08
   OUTLET VOLUMETRIC FLOW RATE, CUFT/HR                5,612,160.
   INLET  COMPRESSIBILITY FACTOR                               0.99954
   OUTLET COMPRESSIBILITY FACTOR                               1.00111
   AV. ISENT. VOL. EXPONENT                                    1.24738
   AV. ISENT. TEMP EXPONENT                                    1.24561
   AV. ACTUAL VOL. EXPONENT                                    1.29308
   AV. ACTUAL TEMP EXPONENT                                    1.29090

 BLOCK:  C-105    MODEL: COMPR
 -----------------------------
  INLET STREAM:          S-116
  OUTLET STREAM:         S-117
  PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

                     ***  MASS AND ENERGY BALANCE  ***
                                  IN               OUT        RELATIVE DIFF.
   TOTAL BALANCE
      MOLE(LBMOL/HR)           50507.1         50507.1          0.00000
      MASS(LB/HR   )           809463.         809463.         0.143818E-15
      ENTHALPY(BTU/HR  )     -0.144806E+10   -0.133397E+10   -0.787881E-01

                     ***  CO2 EQUIVALENT SUMMARY ***
   FEED STREAMS CO2E           0.156540E+08  LB/HR
   PRODUCT STREAMS CO2E        0.156540E+08  LB/HR
   NET STREAMS CO2E PRODUCTION   0.00000      LB/HR
   UTILITIES CO2E PRODUCTION     0.00000      LB/HR
   TOTAL CO2E PRODUCTION         0.00000      LB/HR

                          ***  INPUT DATA  ***

  ISENTROPIC CENTRIFUGAL COMPRESSOR
   OUTLET PRESSURE  PSIA                                      90.0000
```

```
 ISENTROPIC EFFICIENCY                                         0.85000
 MECHANICAL EFFICIENCY                                         1.00000

                       ***  RESULTS  ***

 INDICATED  HORSEPOWER REQUIREMENT  HP                  44,839.1
 BRAKE      HORSEPOWER REQUIREMENT  HP                  44,839.1
 NET WORK REQUIRED                  HP                  44,839.1
 POWER LOSSES                       HP                       0.0
 ISENTROPIC HORSEPOWER REQUIREMENT  HP                  38,113.2
 CALCULATED OUTLET TEMP  F                                 471.192
 ISENTROPIC TEMPERATURE  F                                 440.155
 EFFICIENCY (POLYTR/ISENTR) USED                               0.85000
 OUTLET VAPOR FRACTION                                         1.00000
 HEAD DEVELOPED,       FT-LBF/LB                        93,227.5
 MECHANICAL EFFICIENCY USED                                    1.00000
 INLET HEAT CAPACITY RATIO                                     1.26736
 INLET VOLUMETRIC FLOW RATE , CUFT/HR                          0.142397+08
 OUTLET VOLUMETRIC FLOW RATE, CUFT/HR                5,612,210.
 INLET  COMPRESSIBILITY FACTOR                                 0.99954
 OUTLET COMPRESSIBILITY FACTOR                                 1.00111
 AV. ISENT. VOL. EXPONENT                                      1.24738
 AV. ISENT. TEMP EXPONENT                                      1.24561
 AV. ACTUAL VOL. EXPONENT                                      1.29308
 AV. ACTUAL TEMP EXPONENT                                      1.29090

BLOCK:  C-106    MODEL: COMPR
-----------------------------
  INLET STREAM:          S-118
  OUTLET STREAM:         S-119
  PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

                  ***  MASS AND ENERGY BALANCE  ***
                                 IN              OUT        RELATIVE DIFF.
   TOTAL BALANCE
      MOLE(LBMOL/HR)          50507.6         50507.6         0.00000
      MASS(LB/HR   )          809471.         809471.         0.00000
      ENTHALPY(BTU/HR  )    -0.144808E+10   -0.133281E+10   -0.795999E-01

                  ***  CO2 EQUIVALENT SUMMARY ***
   FEED STREAMS CO2E            0.156542E+08  LB/HR
   PRODUCT STREAMS CO2E         0.156542E+08  LB/HR
   NET STREAMS CO2E PRODUCTION   0.00000      LB/HR
   UTILITIES CO2E PRODUCTION     0.00000      LB/HR
   TOTAL CO2E PRODUCTION         0.00000      LB/HR

                       ***  INPUT DATA  ***

  ISENTROPIC CENTRIFUGAL COMPRESSOR
   OUTLET PRESSURE  PSIA                                      91.0000
   ISENTROPIC EFFICIENCY                                       0.85000
   MECHANICAL EFFICIENCY                                       1.00000

                       ***  RESULTS  ***

   INDICATED  HORSEPOWER REQUIREMENT  HP                  45,301.6
   BRAKE      HORSEPOWER REQUIREMENT  HP                  45,301.6
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```
   NET WORK REQUIRED                    HP                45,301.6
   POWER LOSSES                         HP                     0.0
   ISENTROPIC HORSEPOWER REQUIREMENT    HP                38,506.3
   CALCULATED OUTLET TEMP  F                                 473.313
   ISENTROPIC TEMPERATURE  F                                 441.996
   EFFICIENCY (POLYTR/ISENTR) USED                             0.85000
   OUTLET VAPOR FRACTION                                       1.00000
   HEAD DEVELOPED,       FT-LBF/LB                    94,188.1
   MECHANICAL EFFICIENCY USED                                  1.00000
   INLET HEAT CAPACITY RATIO                                   1.26736
   INLET VOLUMETRIC FLOW RATE , CUFT/HR                        0.142398+08
   OUTLET VOLUMETRIC FLOW RATE, CUFT/HR                5,563,380.
   INLET  COMPRESSIBILITY FACTOR                               0.99954
   OUTLET COMPRESSIBILITY FACTOR                               1.00114
   AV. ISENT. VOL. EXPONENT                                    1.24722
   AV. ISENT. TEMP EXPONENT                                    1.24544
   AV. ACTUAL VOL. EXPONENT                                    1.29280
   AV. ACTUAL TEMP EXPONENT                                    1.29061

BLOCK:  C-401    MODEL: COMPR
-----------------------------
  INLET STREAM:          S-403
  OUTLET STREAM:         S-404
  PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

                    ***  MASS AND ENERGY BALANCE  ***
                                 IN               OUT        RELATIVE DIFF.
   TOTAL BALANCE
      MOLE(LBMOL/HR)           5225.92         5225.92         0.00000
      MASS(LB/HR   )           78268.1         78268.1       -0.185924E-15
      ENTHALPY(BTU/HR  )     -0.167896E+09   -0.165398E+09   -0.148820E-01

                    ***  CO2 EQUIVALENT SUMMARY ***
   FEED STREAMS CO2E           0.164348E+07  LB/HR
   PRODUCT STREAMS CO2E        0.164348E+07  LB/HR
   NET STREAMS CO2E PRODUCTION   0.00000     LB/HR
   UTILITIES CO2E PRODUCTION     0.00000     LB/HR
   TOTAL CO2E PRODUCTION         0.00000     LB/HR

                         ***  INPUT DATA  ***

  ISENTROPIC CENTRIFUGAL COMPRESSOR
   OUTLET PRESSURE  PSIA                                      44.0878
   ISENTROPIC EFFICIENCY                                       0.85000
   MECHANICAL EFFICIENCY                                       1.00000

                         ***  RESULTS  ***

   INDICATED  HORSEPOWER REQUIREMENT    HP                   982.003
   BRAKE      HORSEPOWER REQUIREMENT    HP                   982.003
   NET WORK REQUIRED                    HP                   982.003
   POWER LOSSES                         HP                     0.0
   ISENTROPIC HORSEPOWER REQUIREMENT    HP                   834.702
   CALCULATED OUTLET TEMP  F                                  28.5895
   ISENTROPIC TEMPERATURE  F                                  19.7594
   EFFICIENCY (POLYTR/ISENTR) USED                             0.85000
   OUTLET VAPOR FRACTION                                       1.00000
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   HEAD DEVELOPED,       FT-LBF/LB                      21,116.0
   MECHANICAL EFFICIENCY USED                                1.00000
   INLET HEAT CAPACITY RATIO                                 1.34530
   INLET VOLUMETRIC FLOW RATE , CUFT/HR                852,368.
   OUTLET VOLUMETRIC FLOW RATE, CUFT/HR                617,991.
   INLET  COMPRESSIBILITY FACTOR                             0.99482
   OUTLET COMPRESSIBILITY FACTOR                             0.99502
   AV. ISENT. VOL. EXPONENT                                  1.33457
   AV. ISENT. TEMP EXPONENT                                  1.33525
   AV. ACTUAL VOL. EXPONENT                                  1.41188
   AV. ACTUAL TEMP EXPONENT                                  1.41099

BLOCK:  C-402    MODEL: COMPR
-----------------------------
  INLET STREAM:          S-405
  OUTLET STREAM:         S-406
  PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

                    ***  MASS AND ENERGY BALANCE  ***
                                 IN              OUT        RELATIVE DIFF.
   TOTAL BALANCE
      MOLE(LBMOL/HR)           70000.0        70000.0         0.00000
      MASS(LB/HR   )          0.201953E+07    0.201953E+07     0.00000
      ENTHALPY(BTU/HR  )       0.419584E+07    0.119328E+09   -0.964838

                    ***  CO2 EQUIVALENT SUMMARY ***
   FEED STREAMS CO2E            0.00000      LB/HR
   PRODUCT STREAMS CO2E         0.00000      LB/HR
   NET STREAMS CO2E PRODUCTION  0.00000      LB/HR
   UTILITIES CO2E PRODUCTION    0.00000      LB/HR
   TOTAL CO2E PRODUCTION        0.00000      LB/HR

                         ***  INPUT DATA  ***

  ISENTROPIC CENTRIFUGAL COMPRESSOR
   OUTLET PRESSURE  PSIA                                    44.0878
   ISENTROPIC EFFICIENCY                                     0.85000
   MECHANICAL EFFICIENCY                                     1.00000

                         ***  RESULTS  ***

   INDICATED  HORSEPOWER REQUIREMENT  HP                45,248.7
   BRAKE      HORSEPOWER REQUIREMENT  HP                45,248.7
   NET WORK REQUIRED                  HP                45,248.7
   POWER LOSSES                       HP                     0.0
   ISENTROPIC HORSEPOWER REQUIREMENT  HP                38,461.4
   CALCULATED OUTLET TEMP  F                               320.686
   ISENTROPIC TEMPERATURE  F                               285.777
   EFFICIENCY (POLYTR/ISENTR) USED                           0.85000
   OUTLET VAPOR FRACTION                                     1.00000
   HEAD DEVELOPED,       FT-LBF/LB                      37,708.6
   MECHANICAL EFFICIENCY USED                                1.00000
   INLET HEAT CAPACITY RATIO                                 1.40077
   INLET VOLUMETRIC FLOW RATE , CUFT/HR                      0.278894+08
   OUTLET VOLUMETRIC FLOW RATE, CUFT/HR                      0.133116+08
   INLET  COMPRESSIBILITY FACTOR                             0.99989
   OUTLET COMPRESSIBILITY FACTOR                             1.00116
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  AV. ISENT. VOL. EXPONENT                                  1.39869
  AV. ISENT. TEMP EXPONENT                                  1.39658
  AV. ACTUAL VOL. EXPONENT                                  1.48540
  AV. ACTUAL TEMP EXPONENT                                  1.48285

BLOCK:  COL-101  MODEL: FLASH2
------------------------------
  INLET STREAM:          S-123
  OUTLET VAPOR STREAM:   S-125
  OUTLET LIQUID STREAM:  S-124
  PROPERTY OPTION SET:   SRK      SOAVE-REDLICH-KWONG EQUATION OF STATE

                    ***  MASS AND ENERGY BALANCE  ***
                                  IN              OUT         RELATIVE DIFF.
  TOTAL BALANCE
     MOLE(LBMOL/HR)           151521.         151521.         0.00000
     MASS(LB/HR   )          0.242839E+07    0.242839E+07     0.00000
     ENTHALPY(BTU/HR  )     -0.475314E+10   -0.475314E+10    0.116151E-11

                    ***  CO2 EQUIVALENT SUMMARY ***
  FEED STREAMS CO2E             0.469622E+08  LB/HR
  PRODUCT STREAMS CO2E          0.469622E+08  LB/HR
  NET STREAMS CO2E PRODUCTION    0.00000      LB/HR
  UTILITIES CO2E PRODUCTION      0.00000      LB/HR
  TOTAL CO2E PRODUCTION          0.00000      LB/HR

                        ***  INPUT DATA  ***
  TWO    PHASE  PQ  FLASH
  PRESSURE DROP        PSI                                 16.0000
  SPECIFIED HEAT DUTY  BTU/HR                               0.0
  MAXIMUM NO. ITERATIONS                                   30
  CONVERGENCE TOLERANCE                                     0.100000-05

                         ***  RESULTS  ***
  OUTLET TEMPERATURE    F                                  -31.888
  OUTLET PRESSURE       PSIA                                28.000
  VAPOR FRACTION                                            0.98542


  V-L PHASE EQUILIBRIUM :

     COMP             F(I)           X(I)           Y(I)           K(I)
     BENZENE          0.12813E-01    0.77454        0.15425E-02    0.19915E-
02
     TOLUENE          0.59137E-03    0.39150E-01    0.20861E-04    0.53285E-
03
     P-XYLENE         0.39424E-05    0.26913E-03    0.18664E-07    0.69347E-
04
     M-XYLENE         0.39424E-05    0.26925E-03    0.16942E-07    0.62921E-
04
     O-XYLENE         0.39424E-05    0.26954E-03    0.12645E-07    0.46911E-
04
     METHANE          0.76878        0.60282E-02    0.78006        129.40
     N2               0.12208E-01    0.18713E-04    0.12389E-01    662.04
     H2               0.16558        0.64952E-04    0.16803        2587.0
     CO               0.98561E-03    0.18071E-05    0.10002E-02    553.48
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     CO2              0.36468E-01    0.36425E-02    0.36953E-01     10.145
     NAPTH             0.25626E-02    0.17575        0.10937E-06    0.62229E-
06

 BLOCK:  COL-201  MODEL: RADFRAC
 -------------------------------
    INLETS   - S-205    STAGE  17
    OUTLETS  - S-206    STAGE   1
               S-207    STAGE  34
               Q-201    STAGE  34
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

                      ***  MASS AND ENERGY BALANCE  ***
                                    IN              OUT        RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(LBMOL/HR)            2325.35         2325.35       -0.195561E-15
       MASS(LB/HR   )            204221.         204221.        0.178139E-13
       ENTHALPY(BTU/HR  )       0.593469E+08    0.143631E+08    0.757981

                      ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E              0.00000      LB/HR
    PRODUCT STREAMS CO2E           0.00000      LB/HR
    NET STREAMS CO2E PRODUCTION    0.00000      LB/HR
    UTILITIES CO2E PRODUCTION      0.00000      LB/HR
    TOTAL CO2E PRODUCTION          0.00000      LB/HR


                         **********************
                         ****  INPUT DATA  ****
                         **********************

   ****   INPUT PARAMETERS   ****

    NUMBER OF STAGES                                        34
    ALGORITHM OPTION                                      STANDARD
    ABSORBER OPTION                                       NO
    INITIALIZATION OPTION                                 STANDARD
    HYDRAULIC PARAMETER CALCULATIONS                      NO
    INSIDE LOOP CONVERGENCE METHOD                        BROYDEN
    DESIGN SPECIFICATION METHOD                           NESTED
    MAXIMUM NO. OF OUTSIDE LOOP ITERATIONS                  25
    MAXIMUM NO. OF INSIDE LOOP ITERATIONS                   10
    MAXIMUM NUMBER OF FLASH ITERATIONS                      30
    FLASH TOLERANCE                                          0.100000-05
    OUTSIDE LOOP CONVERGENCE TOLERANCE                       0.000100000

   ****   COL-SPECS   ****

    MOLAR VAPOR DIST / TOTAL DIST                            0.0
    MOLAR REFLUX RATIO                                       1.00000
    DISTILLATE TO FEED RATIO                                 0.75700

   ****    PROFILES   ****

    P-SPEC          STAGE   1  PRES, PSIA                   30.0000
```

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                    ******************
                    ****  RESULTS  ****
                    ******************


 ***   COMPONENT SPLIT FRACTIONS   ***

                         OUTLET STREAMS
                         --------------
              S-206        S-207
  COMPONENT:
  BENZENE     1.0000       .19714E-05
  TOLUENE     .22710       .77290
  P-XYLENE    .18436E-06   1.0000
  M-XYLENE    .11955E-06   1.0000
  O-XYLENE    .90850E-08   1.0000
  METHANOL    1.0000       .92113E-12
  WATER       1.0000       .39394E-13
  NAPTH       0.0000       1.0000


 ***    SUMMARY OF KEY RESULTS    ***

  TOP STAGE TEMPERATURE          F                        221.738
  BOTTOM STAGE TEMPERATURE       F                        387.892
  TOP STAGE LIQUID FLOW          LBMOL/HR               1,760.29
  BOTTOM STAGE LIQUID FLOW       LBMOL/HR                 565.059
  TOP STAGE VAPOR FLOW           LBMOL/HR                   0.0
  BOILUP VAPOR FLOW              LBMOL/HR               2,987.62
  MOLAR REFLUX RATIO                                        1.00000
  MOLAR BOILUP RATIO                                        5.28727
  CONDENSER DUTY (W/O SUBCOOL)   BTU/HR                    -0.449838+08
  REBOILER DUTY                  BTU/HR                     0.546206+08

 ****   MAXIMUM FINAL RELATIVE ERRORS   ****

  DEW POINT                        0.15845E-06  STAGE= 21
  BUBBLE POINT                     0.29807E-07  STAGE= 20
  COMPONENT MASS BALANCE           0.47418E-06  STAGE= 22 COMP=NAPTH
  ENERGY BALANCE                   0.68137E-07  STAGE= 33


 ****    PROFILES   ****

 **NOTE** REPORTED VALUES FOR STAGE LIQUID AND VAPOR RATES ARE THE FLOWS
          FROM THE STAGE INCLUDING ANY SIDE PRODUCT.

                                          ENTHALPY
STAGE TEMPERATURE   PRESSURE              BTU/LBMOL           HEAT DUTY
      F             PSIA            LIQUID        VAPOR         BTU/HR

  1   221.74        30.000         24904.       36587.       -.44984+08
  2   223.04        30.150         25181.       37681.
 16   232.23        32.250         24003.       37371.
 17   239.51        32.400         26157.       37582.
 18   242.40        32.550         25563.       37478.
 19   247.22        32.700         24440.       36885.
```

33	322.56	34.800	23994.	28948.	
34	387.89	34.950	44502.	38397.	.54621+08

STAGE	FLOW RATE LBMOL/HR		FEED RATE LBMOL/HR			PRODUCT RATE LBMOL/HR	
	LIQUID	VAPOR	LIQUID	VAPOR	MIXED	LIQUID	VAPOR
1	3521.	0.000				1760.2863	
2	1758.	3521.					
16	1669.	3484.					
17	4474.	3429.	2325.3452				
18	4444.	3909.					
19	4393.	3879.					
33	3553.	3565.					
34	565.1	2988.				565.0589	

**** MASS FLOW PROFILES ****

STAGE	FLOW RATE LB/HR		FEED RATE LB/HR			PRODUCT RATE LB/HR	
	LIQUID	VAPOR	LIQUID	VAPOR	MIXED	LIQUID	VAPOR
1	0.2750E+06	0.000				.13751+06	
2	0.1381E+06	0.2750E+06					
16	0.1344E+06	0.2757E+06					
17	0.3791E+06	0.2719E+06	.20422+06				
18	0.3805E+06	0.3124E+06					
19	0.3823E+06	0.3138E+06					
33	0.3686E+06	0.3376E+06					
34	0.6671E+05	0.3019E+06				.66713+05	

**** MOLE-X-PROFILE ****

STAGE	BENZENE	TOLUENE	P-XYLENE	M-XYLENE	O-XYLENE
1	0.97207	0.21678E-01	0.47893E-08	0.40399E-10	0.30733E-11
2	0.95864	0.38856E-01	0.23929E-07	0.20767E-09	0.18640E-10
16	0.84180	0.14552	0.67095E-02	0.84285E-04	0.68617E-04
17	0.76379	0.13248	0.13279E-01	0.17135E-03	0.16424E-03
18	0.70711	0.18868	0.13765E-01	0.17745E-03	0.16909E-03
19	0.61169	0.28201	0.14699E-01	0.18917E-03	0.17835E-03
33	0.26792E-04	0.59553	0.13140	0.16835E-02	0.14766E-02
34	0.59699E-05	0.22983	0.80928E-01	0.10527E-02	0.10538E-02

**** MOLE-X-PROFILE ****

STAGE	METHANOL	WATER	NAPTH
1	0.53287E-02	0.92293E-03	0.15610E-23
2	0.22139E-02	0.28742E-03	0.86106E-22
16	0.13109E-02	0.16210E-03	0.43495E-02
17	0.12145E-02	0.15537E-03	0.88748E-01
18	0.48426E-03	0.48459E-04	0.89562E-01
19	0.18229E-03	0.14326E-04	0.91042E-01
33	0.15432E-12	0.11010E-14	0.26988

34	0.15291E-13	0.11326E-15	0.68713

**** MOLE-Y-PROFILE ****

STAGE	BENZENE	TOLUENE	P-XYLENE	M-XYLENE	O-XYLENE
1	0.97239	0.12034E-01	0.94726E-09	0.77640E-11	0.49995E-12
2	0.97207	0.21678E-01	0.47893E-08	0.40399E-10	0.30733E-11
16	0.91220	0.82351E-01	0.14372E-02	0.17581E-04	0.12202E-04
17	0.90866	0.81953E-01	0.32656E-02	0.41023E-04	0.33397E-04
18	0.87419	0.11841	0.35002E-02	0.43955E-04	0.35649E-04
19	0.81011	0.18269	0.39822E-02	0.49969E-04	0.40222E-04
33	0.81141E-04	0.86400	0.10352	0.13021E-02	0.99093E-03
34	0.30730E-04	0.66470	0.14095	0.18028E-02	0.15565E-02

**** MOLE-Y-PROFILE ****

STAGE	METHANOL	WATER	NAPTH
1	0.12655E-01	0.29246E-02	0.27663E-25
2	0.53287E-02	0.92293E-03	0.15610E-23
16	0.33460E-02	0.54690E-03	0.89876E-04
17	0.33731E-02	0.55262E-03	0.21170E-02
18	0.13900E-02	0.17783E-03	0.22539E-02
19	0.55479E-03	0.55517E-04	0.25210E-02
33	0.10440E-11	0.82555E-14	0.30105E-01
34	0.18061E-12	0.12879E-14	0.19097

**** K-VALUES ****

STAGE	BENZENE	TOLUENE	P-XYLENE	M-XYLENE	O-XYLENE
1	1.0003	0.55514	0.19779	0.19218	0.16267
2	1.0140	0.55790	0.20015	0.19454	0.16488
16	1.0836	0.56591	0.21420	0.20858	0.17783
17	1.1897	0.61862	0.24593	0.23941	0.20335
18	1.2363	0.62753	0.25428	0.24770	0.21082
19	1.3244	0.64782	0.27092	0.26414	0.22552
33	3.0286	1.4508	0.78780	0.77346	0.67110
34	5.1474	2.8922	1.7416	1.7126	1.4770

**** K-VALUES ****

STAGE	METHANOL	WATER	NAPTH
1	2.3749	3.1689	0.17722E-01
2	2.4069	3.2111	0.18128E-01
16	2.5525	3.3739	0.20663E-01
17	2.7775	3.5568	0.23854E-01
18	2.8704	3.6697	0.25166E-01
19	3.0435	3.8753	0.27690E-01
33	6.7651	7.4980	0.11155
34	11.812	11.371	0.27792

**** MASS-X-PROFILE ****

STAGE	BENZENE	TOLUENE	P-XYLENE	M-XYLENE	O-XYLENE

1	0.97203	0.25569E-01	0.65090E-08	0.54906E-10	0.41769E-11
2	0.95345	0.45585E-01	0.32346E-07	0.28072E-09	0.25197E-10
16	0.81689	0.16657	0.88493E-02	0.11117E-03	0.90501E-04
17	0.70414	0.14406	0.16638E-01	0.21470E-03	0.20579E-03
18	0.64516	0.20307	0.17069E-01	0.22006E-03	0.20968E-03
19	0.54895	0.29853	0.17929E-01	0.23074E-03	0.21754E-03
33	0.20171E-04	0.52888	0.13446	0.17227E-02	0.15109E-02
34	0.39498E-05	0.17936	0.72773E-01	0.94662E-03	0.94764E-03

**** MASS-X-PROFILE ****

STAGE	METHANOL	WATER	NAPTH
1	0.21857E-02	0.21285E-03	0.25612E-23
2	0.90323E-03	0.65928E-04	0.14052E-21
16	0.52181E-03	0.36278E-04	0.69258E-02
17	0.45926E-03	0.33035E-04	0.13425
18	0.18124E-03	0.10197E-04	0.13408
19	0.67105E-04	0.29651E-05	0.13407
33	0.47659E-13	0.19118E-15	0.33341
34	0.41498E-14	0.17283E-16	0.74597

**** MASS-Y-PROFILE ****

STAGE	BENZENE	TOLUENE	P-XYLENE	M-XYLENE	O-XYLENE
1	0.97979	0.14303E-01	0.12973E-08	0.10633E-10	0.68468E-12
2	0.97203	0.25569E-01	0.65090E-08	0.54906E-10	0.41769E-11
16	0.90051	0.95895E-01	0.19283E-02	0.23588E-04	0.16372E-04
17	0.89536	0.95254E-01	0.43734E-02	0.54940E-04	0.44727E-04
18	0.85451	0.13652	0.46501E-02	0.58396E-04	0.47360E-04
19	0.78232	0.20811	0.52267E-02	0.65586E-04	0.52793E-04
33	0.66924E-04	0.84058	0.11604	0.14597E-02	0.11108E-02
34	0.23756E-04	0.60612	0.14809	0.18942E-02	0.16354E-02

**** MASS-Y-PROFILE ****

STAGE	METHANOL	WATER	NAPTH
1	0.52306E-02	0.67964E-03	0.45737E-25
2	0.21857E-02	0.21285E-03	0.25612E-23
16	0.13549E-02	0.12451E-03	0.14558E-03
17	0.13634E-02	0.12558E-03	0.34228E-02
18	0.55734E-03	0.40089E-04	0.36150E-02
19	0.21977E-03	0.12365E-04	0.39947E-02
33	0.35320E-12	0.15704E-14	0.40742E-01
34	0.57274E-13	0.22961E-15	0.24224

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*******************************
***** HYDRAULIC PARAMETERS *****
*******************************
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*** DEFINITIONS ***

```
MARANGONI INDEX = SIGMA - SIGMATO
FLOW PARAM = (ML/MV)*SQRT(RHOV/RHOL)
QR = QV*SQRT(RHOV/(RHOL-RHOV))
F FACTOR = QV*SQRT(RHOV)
  WHERE:
  SIGMA IS THE SURFACE TENSION OF LIQUID FROM THE STAGE
  SIGMATO IS THE SURFACE TENSION OF LIQUID TO THE STAGE
  ML IS THE MASS FLOW OF LIQUID FROM THE STAGE
  MV IS THE MASS FLOW OF VAPOR TO THE STAGE
  RHOL IS THE MASS DENSITY OF LIQUID FROM THE STAGE
  RHOV IS THE MASS DENSITY OF VAPOR TO THE STAGE
  QV IS THE VOLUMETRIC FLOW RATE OF VAPOR TO THE STAGE
```

	TEMPERATURE F	
STAGE	LIQUID FROM	VAPOR TO
1	221.74	223.04
2	223.04	223.97
16	232.23	239.51
17	239.51	242.40
18	242.40	247.22
19	247.22	255.04
33	322.56	387.89
34	387.89	387.89

	MASS FLOW LB/HR		VOLUME FLOW CUFT/HR		MOLECULAR WEIGHT	
STAGE	LIQUID FROM	VAPOR TO	LIQUID FROM	VAPOR TO	LIQUID FROM	VAPOR TO
1	0.27502E+06	0.27502E+06	5611.4	0.81367E+06	78.117	78.117
2	0.13808E+06	0.27559E+06	2820.9	0.81000E+06	78.539	78.328
16	0.13436E+06	0.27187E+06	2769.8	0.75403E+06	80.495	79.274
17	0.37911E+06	0.31240E+06	7641.6	0.85875E+06	84.731	79.913
18	0.38051E+06	0.31379E+06	7692.4	0.85372E+06	85.614	80.888
19	0.38233E+06	0.31561E+06	7764.8	0.84718E+06	87.040	82.460
33	0.36860E+06	0.30189E+06	7568.5	0.73671E+06	103.75	101.05
34	66713.	0.0000	1297.9	0.0000	118.06	

	DENSITY LB/CUFT		VISCOSITY CP		SURFACE TENSION DYNE/CM
STAGE	LIQUID FROM	VAPOR TO	LIQUID FROM	VAPOR TO	LIQUID FROM
1	49.010	0.33800	0.24958	0.97542E-02	17.824
2	48.948	0.34023	0.24798	0.97604E-02	17.768
16	48.508	0.36055	0.23827	0.99204E-02	17.439

17	49.611	0.36378	0.25065	0.99258E-02	18.764
18	49.466	0.36756	0.24757	0.99296E-02	18.698
19	49.239	0.37255	0.24260	0.99325E-02	18.603
33	48.702	0.40978	0.21621	0.10624E-01	18.519
34	51.402		0.26162		21.949

STAGE	MARANGONI INDEX DYNE/CM	FLOW PARAM	QR CUFT/HR	REDUCED F-FACTOR (LB-CUFT)**.5/HR
1		0.83045E-01	67805.	0.47304E+06
2	-.56193E-01	0.41772E-01	67767.	0.47247E+06
16	0.30502E-01	0.42608E-01	65251.	0.45276E+06
17	-3.0988	0.10392	73807.	0.51795E+06
18	-.65625E-01	0.10453	73867.	0.51758E+06
19	-.95367E-01	0.10537	73971.	0.51709E+06
33	1.6972	0.11200	67863.	0.47159E+06
34	3.4299		0.0000	0.0000

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                 ***********************************
                 ***** TRAY SIZING CALCULATIONS *****
                 ***********************************


   *******************
   *** SECTION   1 ***
   *******************

   STARTING STAGE NUMBER                                   2
   ENDING STAGE NUMBER                                    20
   FLOODING CALCULATION METHOD                       GLITSCH

   DESIGN PARAMETERS
   -----------------
   PEAK CAPACITY FACTOR                              1.00000
   SYSTEM FOAMING FACTOR                             1.00000
   FLOODING FACTOR                                   0.80000
   MINIMUM COLUMN DIAMETER          FT               1.00000
   MINIMUM DC AREA/COLUMN AREA                       0.100000
   SLOT AREA/ACTIVE AREA                             0.12000

   TRAY SPECIFICATIONS
   -------------------
   TRAY TYPE                                         BUBBLE CAPS
   NUMBER OF PASSES                                    1
   TRAY SPACING                     FT               2.00000

        ***** SIZING RESULTS @ STAGE WITH MAXIMUM DIAMETER *****

   STAGE WITH MAXIMUM DIAMETER                            20
   COLUMN DIAMETER                  FT              10.9988
   DC AREA/COLUMN AREA                               0.100000
   DOWNCOMER VELOCITY               FT/SEC           0.23038
   FLOW PATH LENGTH                 FT               7.55671
```

SIDE DOWNCOMER WIDTH	FT	1.72104
SIDE WEIR LENGTH	FT	7.99185
CENTER DOWNCOMER WIDTH	FT	0.0
CENTER WEIR LENGTH	FT	0.0
OFF-CENTER DOWNCOMER WIDTH	FT	0.0
OFF-CENTER SHORT WEIR LENGTH	FT	0.0
OFF-CENTER LONG WEIR LENGTH	FT	0.0
TRAY CENTER TO OCDC CENTER	FT	0.0

**** SIZING PROFILES ****

STAGE	DIAMETER	TOTAL AREA	ACTIVE AREA	SIDE DC AREA
	FT	SQFT	SQFT	SQFT
2	9.5999	72.380	57.904	7.2380
3	9.5944	72.298	57.839	7.2298
4	9.5875	72.193	57.755	7.2193
5	9.5800	72.081	57.665	7.2081
6	9.5722	71.964	57.571	7.1964
7	9.5642	71.844	57.475	7.1844
8	9.5560	71.721	57.377	7.1721
9	9.5477	71.596	57.277	7.1596
10	9.5392	71.469	57.175	7.1469
11	9.5307	71.340	57.072	7.1340
12	9.5219	71.210	56.968	7.1210
13	9.5130	71.076	56.861	7.1076
14	9.5036	70.937	56.749	7.0937
15	9.4911	70.749	56.599	7.0749
16	9.4235	69.745	55.796	6.9745
17	10.918	93.625	74.900	9.3625
18	10.933	93.876	75.101	9.3876
19	10.955	94.254	75.403	9.4254
20	10.999	95.012	76.010	9.5012

BLOCK: COL-202 MODEL: RADFRAC

INLETS	- S-207	STAGE	27
OUTLETS	- S-208	STAGE	1
	S-209	STAGE	33
	Q-202	STAGE	33

PROPERTY OPTION SET: SRK   SOAVE-REDLICH-KWONG EQUATION OF STATE

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(LBMOL/HR)	565.059	565.059	0.00000
MASS(LB/HR)	66713.5	66713.5	0.479222E-12
ENTHALPY(BTU/HR)	0.251463E+08	0.142547E+08	0.433131

*** CO2 EQUIVALENT SUMMARY ***

FEED STREAMS CO2E	0.00000	LB/HR
PRODUCT STREAMS CO2E	0.00000	LB/HR
NET STREAMS CO2E PRODUCTION	0.00000	LB/HR
UTILITIES CO2E PRODUCTION	0.00000	LB/HR
TOTAL CO2E PRODUCTION	0.00000	LB/HR

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                    *********************
                    ****  INPUT DATA  ****
                    *********************

****   INPUT PARAMETERS   ****

 NUMBER OF STAGES                                            33
 ALGORITHM OPTION                                          STANDARD
 ABSORBER OPTION                                           NO
 INITIALIZATION OPTION                                     STANDARD
 HYDRAULIC PARAMETER CALCULATIONS                          NO
 INSIDE LOOP CONVERGENCE METHOD                            BROYDEN
 DESIGN SPECIFICATION METHOD                               NESTED
 MAXIMUM NO. OF OUTSIDE LOOP ITERATIONS                      25
 MAXIMUM NO. OF INSIDE LOOP ITERATIONS                       10
 MAXIMUM NUMBER OF FLASH ITERATIONS                          30
 FLASH TOLERANCE                                              0.100000-05
 OUTSIDE LOOP CONVERGENCE TOLERANCE                           0.000100000

****   COL-SPECS   ****

 MOLAR VAPOR DIST / TOTAL DIST                                0.0
 MOLAR REFLUX RATIO                                           5.00000
 MOLAR DISTILLATE RATE          LBMOL/HR                    127.000

****    PROFILES   ****

 P-SPEC          STAGE   1  PRES, PSIA                       20.0000

                     ******************
                     ****  RESULTS  ****
                     ******************


***   COMPONENT SPLIT FRACTIONS   ***

                        OUTLET STREAMS
                        --------------
              S-208        S-209
 COMPONENT:
 BENZENE     .99988       .12386E-03
 TOLUENE     .97791       .22091E-01
 P-XYLENE    .25817E-05   1.0000
 M-XYLENE    .14006E-05   1.0000
 O-XYLENE    .22631E-07   1.0000
 METHANOL    1.0000       .17683E-06
 NAPTH       0.0000       1.0000


***    SUMMARY OF KEY RESULTS    ***

 TOP STAGE TEMPERATURE          F                           251.768
 BOTTOM STAGE TEMPERATURE       F                           429.135
 TOP STAGE LIQUID FLOW          LBMOL/HR                    635.000
 BOTTOM STAGE LIQUID FLOW       LBMOL/HR                    438.059
 TOP STAGE VAPOR FLOW           LBMOL/HR                      0.0
```

BOILUP VAPOR FLOW	LBMOL/HR	524.989
MOLAR REFLUX RATIO		5.00000
MOLAR BOILUP RATIO		1.19844
CONDENSER DUTY (W/O SUBCOOL)	BTU/HR	-0.108916+08
REBOILER DUTY	BTU/HR	0.112080+08

**** MAXIMUM FINAL RELATIVE ERRORS ****

DEW POINT	0.13874E-06	STAGE= 28	
BUBBLE POINT	0.99384E-07	STAGE= 27	
COMPONENT MASS BALANCE	0.27350E-06	STAGE= 27	COMP=NAPTH
ENERGY BALANCE	0.19146E-06	STAGE= 32	

**** PROFILES ****

NOTE REPORTED VALUES FOR STAGE LIQUID AND VAPOR RATES ARE THE FLOWS FROM THE STAGE INCLUDING ANY SIDE PRODUCT.

STAGE	TEMPERATURE	PRESSURE	ENTHALPY BTU/LBMOL		HEAT DUTY
	F	PSIA	LIQUID	VAPOR	BTU/HR
1	251.77	20.000	12250.	26529.	-.10892+08
2	252.27	20.150	12273.	26544.	
15	258.67	22.100	12516.	26724.	
16	259.22	22.250	12507.	26727.	
17	259.84	22.400	12475.	26721.	
25	279.56	23.600	8634.1	24595.	
26	290.86	23.750	11824.	24446.	
27	325.17	23.900	27987.	27823.	
28	331.39	24.050	27673.	27206.	
29	337.97	24.200	27653.	26655.	
30	345.80	24.350	28730.	26623.	
32	387.57	24.650	43049.	36378.	
33	429.14	24.800	54575.	54781.	.11208+08

STAGE	FLOW RATE LBMOL/HR		FEED RATE LBMOL/HR			PRODUCT RATE LBMOL/HR	
	LIQUID	VAPOR	LIQUID	VAPOR	MIXED	LIQUID	VAPOR
1	762.0	0.000				127.0000	
2	635.2	762.0					
15	637.1	764.1					
16	636.9	764.1					
17	636.6	763.9					
25	590.9	737.0					
26	523.1	717.9		52.0133			
27	1000.	598.0	513.0455				
28	1004.	562.3					
29	1007.	566.2					
30	1001.	568.8					
32	963.0	541.1					
33	438.1	525.0				438.0589	

**** MASS FLOW PROFILES ****

STAGE FLOW RATE FEED RATE PRODUCT RATE

	LB/HR		LB/HR			LB/HR	
	LIQUID	VAPOR	LIQUID	VAPOR	MIXED	LIQUID	VAPOR
1	0.7021E+05	0.000				.11702+05	
2	0.5853E+05	0.7021E+05					
15	0.5873E+05	0.7042E+05					
16	0.5874E+05	0.7043E+05					
17	0.5875E+05	0.7044E+05					
25	0.5774E+05	0.7029E+05					
26	0.5314E+05	0.6944E+05		5296.1583			
27	0.1119E+06	0.5954E+05	.61417+05				
28	0.1133E+06	0.5692E+05					
29	0.1146E+06	0.5832E+05					
30	0.1153E+06	0.5962E+05					
32	0.1170E+06	0.5997E+05					
33	0.5501E+05	0.6202E+05				.55012+05	

**** MOLE-X-PROFILE ****

STAGE	BENZENE	TOLUENE	P-XYLENE	M-XYLENE	O-XYLENE
1	0.26559E-04	0.99997	0.92958E-06	0.65602E-08	0.10611E-09
2	0.10050E-04	0.99999	0.19556E-05	0.14116E-07	0.26425E-09
15	0.24955E-05	0.99673	0.32302E-02	0.30840E-04	0.36301E-05
16	0.24983E-05	0.99436	0.55730E-02	0.54380E-04	0.73914E-05
17	0.25002E-05	0.99030	0.95834E-02	0.95564E-04	0.14996E-04
25	0.22855E-05	0.62025	0.36179	0.42562E-02	0.20513E-02
26	0.21059E-05	0.48246	0.41017	0.49174E-02	0.27192E-02
27	0.12426E-05	0.26863	0.29428	0.35881E-02	0.22483E-02
28	0.49603E-06	0.20652	0.35112	0.43085E-02	0.27544E-02
29	0.18845E-06	0.14805	0.40024	0.49563E-02	0.33313E-02
30	0.67291E-07	0.97537E-01	0.42452	0.53160E-02	0.38516E-02
32	0.54401E-08	0.23774E-01	0.25712	0.33035E-02	0.29401E-02
33	0.95379E-09	0.65489E-02	0.10439	0.13579E-02	0.13594E-02

**** MOLE-X-PROFILE ****

STAGE	METHANOL	NAPTH
1	0.68033E-13	0.13141E-29
2	0.12416E-13	0.24813E-28
15	0.24659E-14	0.65553E-13
16	0.24655E-14	0.97789E-12
17	0.24632E-14	0.14490E-10
25	0.20707E-14	0.11646E-01
26	0.18898E-14	0.99735E-01
27	0.75729E-15	0.43126
28	0.12801E-15	0.43530
29	0.20418E-16	0.44342

30	0.30483E-17	0.46877
32	0.44423E-19	0.71286
33	0.34878E-20	0.88634

**** MOLE-Y-PROFILE ****

STAGE	BENZENE	TOLUENE	P-XYLENE	M-XYLENE	O-XYLENE
1	0.70276E-04	0.99993	0.44142E-06	0.30453E-08	0.42558E-10
2	0.26559E-04	0.99997	0.92958E-06	0.65602E-08	0.10611E-09
15	0.64925E-05	0.99842	0.15576E-02	0.14549E-04	0.14827E-05
16	0.64952E-05	0.99727	0.26934E-02	0.25715E-04	0.30267E-05
17	0.64982E-05	0.99530	0.46467E-02	0.45341E-04	0.61626E-05
25	0.65358E-05	0.77118	0.22420	0.25876E-02	0.10893E-02
26	0.65797E-05	0.68743	0.29779	0.35032E-02	0.16884E-02
27	0.53041E-05	0.57874	0.34592	0.41367E-02	0.22343E-02
28	0.22098E-05	0.47280	0.44221	0.53255E-02	0.29408E-02
29	0.87903E-06	0.36122	0.54199	0.65911E-02	0.38336E-02
30	0.33284E-06	0.25704	0.62809	0.77277E-02	0.48499E-02
32	0.38129E-07	0.95385E-01	0.61788	0.78076E-02	0.59985E-02
33	0.91836E-08	0.38148E-01	0.38456	0.49269E-02	0.42591E-02

**** MOLE-Y-PROFILE ****

STAGE	METHANOL	NAPTH
1	0.37316E-12	0.69336E-31
2	0.68033E-13	0.13141E-29
15	0.13364E-13	0.36444E-14
16	0.13364E-13	0.54657E-13
17	0.13366E-13	0.81532E-12
25	0.13531E-13	0.93670E-03
26	0.13740E-13	0.95859E-02
27	0.75543E-14	0.68968E-01
28	0.13472E-14	0.76724E-01
29	0.22704E-15	0.86369E-01
30	0.36141E-16	0.10230
32	0.73757E-18	0.27292
33	0.78581E-19	0.56811

**** K-VALUES ****

STAGE	BENZENE	TOLUENE	P-XYLENE	M-XYLENE	O-XYLENE
1	2.6461	0.99996	0.47486	0.46421	0.40106
2	2.6426	0.99998	0.47535	0.46472	0.40156
15	2.6017	1.0017	0.48220	0.47177	0.40846
16	2.5999	1.0029	0.48330	0.47288	0.40949
17	2.5990	1.0050	0.48487	0.47445	0.41095
25	2.8597	1.2433	0.61968	0.60797	0.53100

26	3.1245	1.4248	0.72602	0.71241	0.62093
27	4.2687	2.1544	1.1755	1.1529	0.99376
28	4.4550	2.2894	1.2594	1.2361	1.0677
29	4.6646	2.4398	1.3542	1.3298	1.1508
30	4.9463	2.6353	1.4795	1.4537	1.2592
32	7.0089	4.0121	2.4031	2.3634	2.0402
33	9.6286	5.8251	3.6839	3.6284	3.1332

**** K-VALUES ****

STAGE	METHANOL	NAPTH
1	5.4850	0.52763E-01
2	5.4796	0.52961E-01
15	5.4194	0.55595E-01
16	5.4205	0.55893E-01
17	5.4262	0.56269E-01
25	6.5346	0.80429E-01
26	7.2709	0.96114E-01
27	9.9754	0.15992
28	10.524	0.17626
29	11.120	0.19478
30	11.856	0.21822
32	16.603	0.38286
33	22.530	0.64095

**** MASS-X-PROFILE ****

STAGE	BENZENE	TOLUENE	P-XYLENE	M-XYLENE	O-XYLENE
1	0.22516E-04	0.99998	0.10711E-05	0.75589E-08	0.12227E-09
2	0.85201E-05	0.99999	0.22533E-05	0.16265E-07	0.30448E-09
15	0.21146E-05	0.99624	0.37201E-02	0.35517E-04	0.41806E-05
16	0.21162E-05	0.99351	0.64159E-02	0.62604E-04	0.85093E-05
17	0.21165E-05	0.98884	0.11026E-01	0.10995E-03	0.17253E-04
25	0.18269E-05	0.58481	0.39306	0.46239E-02	0.22286E-02
26	0.16191E-05	0.43756	0.42863	0.51387E-02	0.28416E-02
27	0.86747E-06	0.22121	0.27923	0.34046E-02	0.21333E-02
28	0.34335E-06	0.16862	0.33032	0.40533E-02	0.25913E-02
29	0.12930E-06	0.11982	0.37324	0.46219E-02	0.31065E-02
30	0.45662E-07	0.78071E-01	0.39153	0.49028E-02	0.35523E-02
32	0.34969E-08	0.18026E-01	0.22463	0.28861E-02	0.25686E-02
33	0.59328E-09	0.48050E-02	0.88253E-01	0.11480E-02	0.11492E-02

**** MASS-X-PROFILE ****

STAGE	METHANOL	NAPTH
1	0.23659E-13	0.18280E-29
2	0.43176E-14	0.34516E-28

15	0.85711E-15	0.91143E-13
16	0.85665E-15	0.13591E-11
17	0.85531E-15	0.20126E-10
25	0.67895E-15	0.15275E-01
26	0.59602E-15	0.12583
27	0.21687E-15	0.49402
28	0.36348E-16	0.49441
29	0.57466E-17	0.49921
30	0.84850E-18	0.52195
32	0.11713E-19	0.75188
33	0.88992E-21	0.90464

**** MASS-Y-PROFILE ****

STAGE	BENZENE	TOLUENE	P-XYLENE	M-XYLENE	O-XYLENE
1	0.59578E-04	0.99994	0.50862E-06	0.35089E-08	0.49037E-10
2	0.22516E-04	0.99998	0.10711E-05	0.75589E-08	0.12227E-09
15	0.55028E-05	0.99818	0.17943E-02	0.16760E-04	0.17080E-05
16	0.55042E-05	0.99686	0.31022E-02	0.29617E-04	0.34860E-05
17	0.55050E-05	0.99458	0.53502E-02	0.52206E-04	0.70957E-05
25	0.53532E-05	0.74506	0.24958	0.28806E-02	0.12126E-02
26	0.53131E-05	0.65477	0.32682	0.38448E-02	0.18530E-02
27	0.41612E-05	0.53557	0.36885	0.44109E-02	0.23824E-02
28	0.17053E-05	0.43037	0.46380	0.55856E-02	0.30844E-02
29	0.66664E-06	0.32313	0.55865	0.67937E-02	0.39515E-02
30	0.24806E-06	0.22596	0.63620	0.78275E-02	0.49126E-02
32	0.26872E-07	0.79296E-01	0.59186	0.74788E-02	0.57459E-02
33	0.60725E-08	0.29754E-01	0.34561	0.44279E-02	0.38277E-02

**** MASS-Y-PROFILE ****

STAGE	METHANOL	NAPTH
1	0.12977E-12	0.96453E-31
2	0.23659E-13	0.18280E-29
15	0.46462E-14	0.50684E-14
16	0.46456E-14	0.76000E-13
17	0.46446E-14	0.11334E-11
25	0.45461E-14	0.12589E-02
26	0.45513E-14	0.12701E-01
27	0.24311E-14	0.88783E-01
28	0.42647E-15	0.97151E-01
29	0.70630E-16	0.10748
30	0.11048E-16	0.12510
32	0.21323E-18	0.31562
33	0.21314E-19	0.61638

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*******************************
***** HYDRAULIC PARAMETERS *****
*******************************
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*** DEFINITIONS ***

```
MARANGONI INDEX = SIGMA - SIGMATO
FLOW PARAM = (ML/MV)*SQRT(RHOV/RHOL)
QR = QV*SQRT(RHOV/(RHOL-RHOV))
F FACTOR = QV*SQRT(RHOV)
  WHERE:
  SIGMA IS THE SURFACE TENSION OF LIQUID FROM THE STAGE
  SIGMATO IS THE SURFACE TENSION OF LIQUID TO THE STAGE
  ML IS THE MASS FLOW OF LIQUID FROM THE STAGE
  MV IS THE MASS FLOW OF VAPOR TO THE STAGE
  RHOL IS THE MASS DENSITY OF LIQUID FROM THE STAGE
  RHOV IS THE MASS DENSITY OF VAPOR TO THE STAGE
  QV IS THE VOLUMETRIC FLOW RATE OF VAPOR TO THE STAGE
```

	TEMPERATURE F	
STAGE	LIQUID FROM	VAPOR TO
1	251.77	252.27
2	252.27	252.77
15	258.67	259.22
16	259.22	259.84
17	259.84	260.56
25	279.56	290.86
26	290.86	328.40
27	325.17	331.39
28	331.39	337.97
29	337.97	345.80
30	345.80	359.31
32	387.57	429.14
33	429.14	429.14

	MASS FLOW LB/HR		VOLUME FLOW CUFT/HR		MOLECULAR WEIGHT	
STAGE	LIQUID FROM	VAPOR TO	LIQUID FROM	VAPOR TO	LIQUID FROM	VAPOR TO
1	70211.	70211.	1466.7	0.27717E+06	92.140	92.140
2	58526.	70228.	1223.2	0.27531E+06	92.140	92.140
15	58728.	70430.	1234.7	0.25330E+06	92.186	92.179
16	58738.	70440.	1235.5	0.25172E+06	92.220	92.206
17	58745.	70447.	1236.4	0.25013E+06	92.276	92.254
25	57741.	69443.	1231.9	0.23225E+06	97.723	96.736
26	53139.	64841.	1115.0	0.22164E+06	101.59	99.748
27	0.11193E+06	56918.	2210.7	0.18976E+06	111.89	101.22
28	0.11334E+06	58324.	2248.4	0.19130E+06	112.85	103.00
29	0.11463E+06	59617.	2282.3	0.19272E+06	113.85	104.81
30	0.11525E+06	60239.	2295.1	0.19280E+06	115.12	106.97
32	0.11703E+06	62019.	2269.5	0.19281E+06	121.52	118.13

33	55012.	0.0000	1056.8	0.0000	125.58

STAGE	DENSITY LB/CUFT LIQUID FROM	DENSITY LB/CUFT VAPOR TO	VISCOSITY CP LIQUID FROM	VISCOSITY CP VAPOR TO	SURFACE TENSION DYNE/CM LIQUID FROM
1	47.869	0.25332	0.21906	0.92304E-02	17.180
2	47.847	0.25509	0.21853	0.92380E-02	17.423
15	47.565	0.27805	0.21202	0.93340E-02	17.051
16	47.541	0.27984	0.21152	0.93414E-02	17.022
17	47.514	0.28164	0.21101	0.93490E-02	16.918
25	46.873	0.29900	0.20481	0.94913E-02	16.604
26	47.658	0.29255	0.21531	0.98288E-02	17.148
27	50.631	0.29996	0.25960	0.97858E-02	21.261
28	50.408	0.30488	0.25739	0.97793E-02	20.942
29	50.226	0.30935	0.25582	0.97909E-02	20.868
30	50.215	0.31245	0.25676	0.98694E-02	20.674
32	51.567	0.32165	0.27925	0.10435E-01	22.129
33	52.057		0.28655		22.428

STAGE	MARANGONI INDEX DYNE/CM	FLOW PARAM	QR CUFT/HR	REDUCED F-FACTOR (LB-CUFT)**.5/HR
1		0.72745E-01	20216.	0.13950E+06
2	0.24343	0.60849E-01	20156.	0.13905E+06
15	-.28483E-01	0.63754E-01	19423.	0.13356E+06
16	-.29060E-01	0.63977E-01	19369.	0.13316E+06
17	-.10389	0.64202E-01	19315.	0.13274E+06
25	-.44551E-01	0.66410E-01	18609.	0.12700E+06
26	0.54460	0.64210E-01	17419.	0.11988E+06
27	0.50428	0.15136	14649.	0.10393E+06
28	-.31881	0.15112	14923.	0.10563E+06
29	-.74216E-01	0.15090	15171.	0.10719E+06
30	-.19353	0.15092	15256.	0.10777E+06
32	1.0184	0.14903	15276.	0.10935E+06
33	0.29979		0.0000	0.0000

```
************************************
***** TRAY SIZING CALCULATIONS *****
************************************


*******************
*** SECTION   1 ***
*******************

STARTING STAGE NUMBER                                   2
ENDING STAGE NUMBER                                    23
FLOODING CALCULATION METHOD                          B960

DESIGN PARAMETERS
-----------------
PEAK CAPACITY FACTOR                                 1.00000
SYSTEM FOAMING FACTOR                                1.00000
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FLOODING FACTOR                                            0.80000
MINIMUM COLUMN DIAMETER        FT                          1.00000
MINIMUM DC AREA/COLUMN AREA                                0.100000

TRAY SPECIFICATIONS
-------------------
TRAY TYPE                                                  FLEXI
NUMBER OF PASSES                                               1
TRAY SPACING                   FT                          2.00000


        ***** SIZING RESULTS @ STAGE WITH MAXIMUM DIAMETER *****

STAGE WITH MAXIMUM DIAMETER                                    2
COLUMN DIAMETER                FT                          5.02122
DC AREA/COLUMN AREA                                        0.10000
DOWNCOMER VELOCITY             FT/SEC                      0.17158
FLOW PATH LENGTH               FT                          3.44982
SIDE DOWNCOMER WIDTH           FT                          0.78570
SIDE WEIR LENGTH               FT                          3.64848
CENTER DOWNCOMER WIDTH         FT                          0.0
CENTER WEIR LENGTH             FT                          0.0
OFF-CENTER DOWNCOMER WIDTH     FT                          0.0
OFF-CENTER SHORT WEIR LENGTH   FT                          0.0
OFF-CENTER LONG WEIR LENGTH    FT                          0.0
TRAY CENTER TO OCDC CENTER     FT                          0.0


                      **** SIZING PROFILES ****

   STAGE    DIAMETER      TOTAL AREA   ACTIVE AREA   SIDE DC AREA
              FT            SQFT          SQFT           SQFT
      2       5.0212        19.802        15.842         1.9802
      3       5.0150        19.753        15.802         1.9753
      4       5.0088        19.704        15.764         1.9704
      5       5.0027        19.657        15.725         1.9657
      6       4.9967        19.609        15.687         1.9609
      7       4.9907        19.562        15.650         1.9562
      8       4.9848        19.516        15.613         1.9516
      9       4.9789        19.470        15.576         1.9470
     10       4.9731        19.424        15.539         1.9424
     11       4.9673        19.379        15.503         1.9379
     12       4.9616        19.334        15.467         1.9334
     13       4.9559        19.290        15.432         1.9290
     14       4.9502        19.246        15.397         1.9246
     15       4.9445        19.202        15.361         1.9202
     16       4.9389        19.158        15.326         1.9158
     17       4.9331        19.113        15.290         1.9113
     18       4.9272        19.067        15.254         1.9067
     19       4.9210        19.020        15.216         1.9020
     20       4.9146        18.970        15.176         1.8970
     21       4.9078        18.918        15.134         1.8918
     22       4.9011        18.866        15.092         1.8866
     23       4.8950        18.819        15.055         1.8819

BLOCK:  COL-203  MODEL: RADFRAC
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 INLETS   - S-210    STAGE   9
 OUTLETS  - S-211    STAGE   1
            S-212    STAGE  14
            Q-203    STAGE  14
PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

                   ***  MASS AND ENERGY BALANCE  ***
                                 IN              OUT        RELATIVE DIFF.
 TOTAL BALANCE
    MOLE(LBMOL/HR)            438.059         438.059         0.00000
    MASS(LB/HR   )            55011.7         55011.7        0.142843E-12
    ENTHALPY(BTU/HR  )       0.239124E+08    0.202721E+08    0.152235

                   ***  CO2 EQUIVALENT SUMMARY ***
 FEED STREAMS CO2E             0.00000      LB/HR
 PRODUCT STREAMS CO2E          0.00000      LB/HR
 NET STREAMS CO2E PRODUCTION   0.00000      LB/HR
 UTILITIES CO2E PRODUCTION     0.00000      LB/HR
 TOTAL CO2E PRODUCTION         0.00000      LB/HR



                      **********************
                      ****  INPUT DATA  ****
                      **********************

****   INPUT PARAMETERS   ****

 NUMBER OF STAGES                                              14
 ALGORITHM OPTION                                            STANDARD
 ABSORBER OPTION                                             NO
 INITIALIZATION OPTION                                       STANDARD
 HYDRAULIC PARAMETER CALCULATIONS                            NO
 INSIDE LOOP CONVERGENCE METHOD                              BROYDEN
 DESIGN SPECIFICATION METHOD                                 NESTED
 MAXIMUM NO. OF OUTSIDE LOOP ITERATIONS                        25
 MAXIMUM NO. OF INSIDE LOOP ITERATIONS                         10
 MAXIMUM NUMBER OF FLASH ITERATIONS                            30
 FLASH TOLERANCE                                                0.100000-05
 OUTSIDE LOOP CONVERGENCE TOLERANCE                             0.000100000

****   COL-SPECS   ****

 MOLAR VAPOR DIST / TOTAL DIST                                  0.0
 MOLAR REFLUX RATIO                                             3.72787
 MOLAR DISTILLATE RATE          LBMOL/HR                       48.6000

****    PROFILES   ****

 P-SPEC          STAGE   1  PRES, PSIA                         14.6959

                       ******************
                       ****  RESULTS  ****
                       ******************


***   COMPONENT SPLIT FRACTIONS   ***
```

OUTLET STREAMS

	S-211	S-212
COMPONENT:		
BENZENE	.99993	.67981E-04
TOLUENE	.99831	.16921E-02
P-XYLENE	.97476	.25237E-01
M-XYLENE	.97240	.27598E-01
O-XYLENE	.93925	.60745E-01
NAPTH	.60086E-04	.99994

*** SUMMARY OF KEY RESULTS ***

TOP STAGE TEMPERATURE	F	277.747
BOTTOM STAGE TEMPERATURE	F	433.528
TOP STAGE LIQUID FLOW	LBMOL/HR	181.175
BOTTOM STAGE LIQUID FLOW	LBMOL/HR	389.459
TOP STAGE VAPOR FLOW	LBMOL/HR	0.0
BOILUP VAPOR FLOW	LBMOL/HR	171.762
MOLAR REFLUX RATIO		3.72787
MOLAR BOILUP RATIO		0.44103
CONDENSER DUTY (W/O SUBCOOL)	BTU/HR	-3,640,300.
REBOILER DUTY	BTU/HR	3,320,720.

**** MAXIMUM FINAL RELATIVE ERRORS ****

DEW POINT	0.70465E-06	STAGE= 6	
BUBBLE POINT	0.16748E-05	STAGE= 6	
COMPONENT MASS BALANCE	0.10098E-06	STAGE= 6	COMP=TOLUENE
ENERGY BALANCE	0.31462E-04	STAGE= 6	

**** PROFILES ****

NOTE REPORTED VALUES FOR STAGE LIQUID AND VAPOR RATES ARE THE FLOWS FROM THE STAGE INCLUDING ANY SIDE PRODUCT.

STAGE	TEMPERATURE F	PRESSURE PSIA	ENTHALPY BTU/LBMOL LIQUID	VAPOR	HEAT DUTY BTU/HR
1	277.75	14.696	-198.99	16190.	-.36403+07
2	280.60	14.846	-297.85	15644.	
3	283.24	14.996	653.26	15608.	
7	393.10	15.596	52748.	52628.	
8	403.06	15.746	54962.	58566.	
9	407.79	15.896	55874.	61291.	
10	415.19	16.046	57319.	66060.	
12	427.19	16.346	59551.	74394.	
13	430.96	16.496	60197.	76986.	
14	433.53	16.646	60603.	78609.	.33207+07

STAGE	FLOW RATE LBMOL/HR LIQUID	VAPOR	FEED RATE LBMOL/HR LIQUID	VAPOR	MIXED	PRODUCT RATE LBMOL/HR LIQUID	VAPOR

```
  1  229.8      0.000                                         48.6000
  2  180.6      229.8
  3  176.6      229.2
  7  134.8      179.7
  8  136.7      183.4                  46.1378
  9  534.6      139.2      391.9210
 10  542.4      145.2
 12  556.4      160.6
 13  561.2      167.0
 14  389.5      171.8                                        389.4589

   ****  MASS FLOW PROFILES  ****

STAGE     FLOW RATE                  FEED RATE                PRODUCT RATE
            LB/HR                      LB/HR                     LB/HR
       LIQUID     VAPOR       LIQUID    VAPOR    MIXED      LIQUID    VAPOR
  1 0.2421E+05  0.000                                      5120.0768
  2 0.1911E+05 0.2421E+05
  3 0.1880E+05 0.2423E+05
  7 0.1697E+05 0.2127E+05
  8 0.1730E+05 0.2209E+05          5515.2431
  9 0.6778E+05 0.1690E+05  .49496+05
 10 0.6900E+05 0.1789E+05
 12 0.7113E+05 0.2027E+05
 13 0.7184E+05 0.2124E+05
 14 0.4989E+05 0.2195E+05                                  .49892+05

                     ****   MOLE-X-PROFILE     ****
   STAGE     BENZENE       TOLUENE       P-XYLENE      M-XYLENE      O-XYLENE
      1     0.85964E-08   0.58929E-01   0.91718       0.11902E-01   0.11508E-
01
      2     0.20826E-08   0.29925E-01   0.94027       0.12424E-01   0.13687E-
01
      3     0.82541E-09   0.17897E-01   0.93190       0.12490E-01   0.15292E-
01
      7     0.21575E-09   0.27904E-02   0.98128E-01   0.13236E-02   0.18213E-
02
      8     0.19374E-09   0.23908E-02   0.69310E-01   0.92352E-03   0.11473E-
02
      9     0.10997E-09   0.17676E-02   0.58461E-01   0.77976E-03   0.96721E-
03
     10     0.29881E-10   0.80149E-03   0.41089E-01   0.55593E-03   0.77897E-
03
     12     0.17552E-11   0.12566E-03   0.14629E-01   0.20327E-03   0.36059E-
03
     13     0.38387E-12   0.43355E-04   0.73186E-02   0.10293E-03   0.20390E-
03
     14     0.72931E-13   0.12465E-04   0.29632E-02   0.42152E-04   0.92878E-
04

                     ****   MOLE-X-PROFILE     ****
   STAGE     NAPTH
      1    0.48003E-03
      2    0.36939E-02
      3    0.22418E-01
      7    0.89594
      8    0.92623
```

9	0.93802
10	0.95678
12	0.98468
13	0.99233
14	0.99689

**** MOLE-Y-PROFILE ****

STAGE	BENZENE	TOLUENE	P-XYLENE	M-XYLENE	O-XYLENE
1	0.34875E-07	0.11297	0.86657	0.11041E-01	0.93638E-02
2	0.85964E-08	0.58929E-01	0.91718	0.11902E-01	0.11508E-01
3	0.34640E-08	0.36076E-01	0.93537	0.12313E-01	0.13225E-01
7	0.25286E-08	0.18969E-01	0.40528	0.53693E-02	0.63195E-02
8	0.24363E-08	0.17665E-01	0.31515	0.41264E-02	0.43880E-02
9	0.14212E-08	0.13501E-01	0.27640	0.36237E-02	0.38494E-02
10	0.40479E-09	0.64759E-02	0.20734	0.27585E-02	0.33127E-02
12	0.25506E-10	0.11047E-02	0.81446E-01	0.11135E-02	0.16953E-02
13	0.56792E-11	0.38971E-03	0.41840E-01	0.57909E-03	0.98506E-03
14	0.10889E-11	0.11340E-03	0.17194E-01	0.24074E-03	0.45565E-03

**** MOLE-Y-PROFILE ****

STAGE	NAPTH
1	0.59653E-04
2	0.48003E-03
3	0.30123E-02
7	0.56406
8	0.65867
9	0.70262
10	0.78011
12	0.91464
13	0.95621
14	0.98200

**** K-VALUES ****

STAGE	BENZENE	TOLUENE	P-XYLENE	M-XYLENE	O-XYLENE
1	4.0569	1.9170	0.94482	0.92766	0.81365
2	4.1277	1.9692	0.97544	0.95799	0.84082
3	4.1967	2.0157	1.0037	0.98580	0.86482
7	11.720	6.7980	4.1301	4.0565	3.4697
8	12.575	7.3885	4.5469	4.4681	3.8245
9	12.923	7.6383	4.7280	4.6472	3.9799
10	13.547	8.0798	5.0462	4.9619	4.2527
12	14.532	8.7912	5.5676	5.4780	4.7015
13	14.795	8.9888	5.7169	5.6261	4.8310
14	14.931	9.0977	5.8025	5.7112	4.9059

**** K-VALUES ****

STAGE NAPTH

1	0.12427
2	0.12995
3	0.13437
7	0.62958
8	0.71114
9	0.74904
10	0.81536
12	0.92887
13	0.96360
14	0.98506

**** MASS-X-PROFILE ****

STAGE	BENZENE	TOLUENE	P-XYLENE	M-XYLENE	O-XYLENE
1	0.63739E-08	0.51539E-01	0.92429	0.11994E-01	0.11597E-01
2	0.15372E-08	0.26055E-01	0.94328	0.12463E-01	0.13731E-01
3	0.60592E-09	0.15497E-01	0.92978	0.12462E-01	0.15257E-01
7	0.13392E-09	0.20431E-02	0.82785E-01	0.11167E-02	0.15366E-02
8	0.11962E-09	0.17412E-02	0.58162E-01	0.77498E-03	0.96279E-03
9	0.67756E-10	0.12846E-02	0.48954E-01	0.65296E-03	0.80992E-03
10	0.18348E-10	0.58053E-03	0.34292E-01	0.46397E-03	0.65011E-03
12	0.10725E-11	0.90575E-04	0.12149E-01	0.16881E-03	0.29947E-03
13	0.23425E-12	0.31208E-04	0.60701E-02	0.85370E-04	0.16912E-03
14	0.44470E-13	0.89652E-05	0.24558E-02	0.34934E-04	0.76973E-04

**** MASS-X-PROFILE ****

STAGE	NAPTH
1	0.58402E-03
2	0.44738E-02
3	0.27003E-01
7	0.91252
8	0.93836
9	0.94830
10	0.96401
12	0.98729
13	0.99364
14	0.99742

**** MASS-Y-PROFILE ****

STAGE	BENZENE	TOLUENE	P-XYLENE	M-XYLENE	O-XYLENE
1	0.26048E-07	0.99526E-01	0.87969	0.11208E-01	0.95055E-02
2	0.63739E-08	0.51539E-01	0.92429	0.11994E-01	0.11597E-01
3	0.25593E-08	0.31440E-01	0.93926	0.12364E-01	0.13280E-01
7	0.16694E-08	0.14773E-01	0.36367	0.48181E-02	0.56707E-02

```
      8    0.15805E-08   0.13517E-01   0.27786        0.36382E-02   0.38688E-
02
      9    0.91418E-09   0.10244E-01   0.24164        0.31680E-02   0.33653E-
02
     10    0.25656E-09   0.48415E-02   0.17861        0.23763E-02   0.28537E-
02
     12    0.15777E-10   0.80606E-03   0.68474E-01   0.93616E-03   0.14253E-
02
     13    0.34875E-11   0.28229E-03   0.34920E-01   0.48332E-03   0.82215E-
03
     14    0.66568E-12   0.81772E-04   0.14286E-01   0.20003E-03   0.37859E-
03

                          ****   MASS-Y-PROFILE     ****
   STAGE     NAPTH
      1    0.73108E-04
      2    0.58402E-03
      3    0.36518E-02
      7    0.61107
      8    0.70112
      9    0.74158
     10    0.81132
     12    0.92836
     13    0.96349
     14    0.98505



                      ********************************
                      ***** HYDRAULIC PARAMETERS *****
                      ********************************


       *** DEFINITIONS ***

        MARANGONI INDEX = SIGMA - SIGMATO
        FLOW PARAM = (ML/MV)*SQRT(RHOV/RHOL)
        QR = QV*SQRT(RHOV/(RHOL-RHOV))
        F FACTOR = QV*SQRT(RHOV)
          WHERE:
          SIGMA IS THE SURFACE TENSION OF LIQUID FROM THE STAGE
          SIGMATO IS THE SURFACE TENSION OF LIQUID TO THE STAGE
          ML IS THE MASS FLOW OF LIQUID FROM THE STAGE
          MV IS THE MASS FLOW OF VAPOR TO THE STAGE
          RHOL IS THE MASS DENSITY OF LIQUID FROM THE STAGE
          RHOV IS THE MASS DENSITY OF VAPOR TO THE STAGE
          QV IS THE VOLUMETRIC FLOW RATE OF VAPOR TO THE STAGE


                      TEMPERATURE
                          F
 STAGE       LIQUID FROM       VAPOR TO
    1          277.75            280.60
    2          280.60            283.24
    3          283.24            290.46
    7          393.10            403.06
```

8	403.06	405.98
9	407.79	415.19
10	415.19	421.90
12	427.19	430.96
13	430.96	433.53
14	433.53	433.53

	MASS FLOW LB/HR		VOLUME FLOW CUFT/HR		MOLECULAR WEIGHT	
STAGE	LIQUID FROM	VAPOR TO	LIQUID FROM	VAPOR TO	LIQUID FROM	VAPOR TO
1	24207.	24207.	515.29	0.11859E+06	105.35	105.35
2	19110.	24230.	407.33	0.11748E+06	105.83	105.73
3	18796.	23917.	399.45	0.11547E+06	106.41	106.18
7	16967.	22087.	316.93	0.10438E+06	125.84	120.41
8	17300.	22420.	323.22	0.10583E+06	126.52	120.97
9	67784.	17893.	1267.3	82129.	126.78	123.24
10	68999.	19108.	1291.3	86322.	127.21	124.93
12	71130.	21238.	1334.2	93374.	127.83	127.20
13	71839.	21947.	1348.8	95429.	128.00	127.78
14	49892.	0.0000	937.51	0.0000	128.10	

	DENSITY LB/CUFT		VISCOSITY CP		SURFACE TENSION DYNE/CM
STAGE	LIQUID FROM	VAPOR TO	LIQUID FROM	VAPOR TO	LIQUID FROM
1	46.978	0.20413	0.22072	0.88588E-02	17.058
2	46.915	0.20625	0.21991	0.88755E-02	16.962
3	47.055	0.20713	0.22179	0.89483E-02	17.102
7	53.535	0.21160	0.32100	0.10016E-01	24.613
8	53.524	0.21185	0.31942	0.10040E-01	24.485
9	53.487	0.21786	0.31809	0.10110E-01	24.377
10	53.432	0.22135	0.31622	0.10161E-01	24.192
12	53.312	0.22745	0.31276	0.10233E-01	23.831
13	53.260	0.22998	0.31145	0.10255E-01	23.681
14	53.217		0.31041		23.560

STAGE	MARANGONI INDEX DYNE/CM	FLOW PARAM	QR CUFT/HR	REDUCED F-FACTOR (LB-CUFT)**.5/HR
1		0.65918E-01	7834.1	53578.
2	-.96843E-01	0.52294E-01	7806.5	53353.
3	0.13992	0.52142E-01	7677.7	52551.
7	0.64531E-01	0.48295E-01	6575.3	48015.
8	-.12819	0.48546E-01	6671.2	48710.
9	-.11879	0.24178	5252.3	38334.
10	-.18471	0.23242	5567.6	40613.
12	-.17856	0.21876	6112.1	44532.
13	-.14960	0.21509	6284.4	45764.
14	-.12065		0.0000	0.0000

****
***** TRAY SIZING CALCULATIONS *****
****

```
*******************
*** SECTION   1 ***
*******************

STARTING STAGE NUMBER                                           2
ENDING STAGE NUMBER                                            13
FLOODING CALCULATION METHOD                               GLITSCH

DESIGN PARAMETERS
-----------------
PEAK CAPACITY FACTOR                                      1.00000
SYSTEM FOAMING FACTOR                                     1.00000
FLOODING FACTOR                                           0.80000
MINIMUM COLUMN DIAMETER          FT                       1.00000
MINIMUM DC AREA/COLUMN AREA                               0.100000
HOLE AREA/ACTIVE AREA                                     0.12000

TRAY SPECIFICATIONS
-------------------
TRAY TYPE                                                 SIEVE
NUMBER OF PASSES                                                1
TRAY SPACING                     FT                       2.00000


        ***** SIZING RESULTS @ STAGE WITH MAXIMUM DIAMETER *****

STAGE WITH MAXIMUM DIAMETER                                     2
COLUMN DIAMETER                  FT                       3.15212
DC AREA/COLUMN AREA                                       0.100000
DOWNCOMER VELOCITY               FT/SEC                   0.14499
FLOW PATH LENGTH                 FT                       2.16566
SIDE DOWNCOMER WIDTH             FT                       0.49323
SIDE WEIR LENGTH                 FT                       2.29037
CENTER DOWNCOMER WIDTH           FT                       0.0
CENTER WEIR LENGTH               FT                       0.0
OFF-CENTER DOWNCOMER WIDTH       FT                       0.0
OFF-CENTER SHORT WEIR LENGTH     FT                       0.0
OFF-CENTER LONG WEIR LENGTH      FT                       0.0
TRAY CENTER TO OCDC CENTER       FT                       0.0


                      **** SIZING PROFILES ****

   STAGE    DIAMETER      TOTAL AREA   ACTIVE AREA   SIDE DC AREA
               FT            SQFT          SQFT          SQFT
     2        3.1521        7.8036        6.2429       0.78036
     3        3.1253        7.6712        6.1370       0.76712
     4        3.0291        7.2065        5.7652       0.72065
     5        2.8734        6.4846        5.1877       0.64846
     6        2.8431        6.3485        5.0788       0.63485
     7        2.8831        6.5284        5.2227       0.65284
     8        2.9048        6.6269        5.3015       0.66269
     9        2.7709        6.0303        4.7663       0.63201
    10        2.8406        6.3373        5.0493       0.64400
    11        2.9093        6.6474        5.3180       0.66474
```

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      12       2.9678        6.9175       5.5340       0.69175
      13       3.0087        7.1096       5.6877       0.71096

BLOCK:  CRYSTAL  MODEL: SEP
---------------------------
  INLET STREAM:          S-215
  OUTLET STREAMS:        S-216       S-217
  PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

                     ***  MASS AND ENERGY BALANCE  ***
                                  IN              OUT        RELATIVE DIFF.
   TOTAL BALANCE
      MOLE(LBMOL/HR)           48.6000         48.6000       -0.146202E-15
      MASS(LB/HR   )           5120.08         5120.08         0.00000
      ENTHALPY(BTU/HR  )      -645751.        -645776.        0.386332E-04

                     ***  CO2 EQUIVALENT SUMMARY ***
   FEED STREAMS CO2E            0.00000      LB/HR
   PRODUCT STREAMS CO2E         0.00000      LB/HR
   NET STREAMS CO2E PRODUCTION  0.00000      LB/HR
   UTILITIES CO2E PRODUCTION    0.00000      LB/HR
   TOTAL CO2E PRODUCTION        0.00000      LB/HR


                         ***  INPUT DATA  ***

  FLASH SPECS FOR STREAM S-216
  TWO    PHASE  TP  FLASH
  PRESSURE DROP        PSI                                  0.0
  MAXIMUM NO. ITERATIONS                                   30
  CONVERGENCE TOLERANCE                                     0.100000-05

  FLASH SPECS FOR STREAM S-217
  TWO    PHASE  TP  FLASH
  PRESSURE DROP        PSI                                  0.0
  MAXIMUM NO. ITERATIONS                                   30
  CONVERGENCE TOLERANCE                                     0.100000-05

  FRACTION OF FEED
    SUBSTREAM= MIXED
      STREAM= S-216     CPT= BENZENE   FRACTION=          0.0
                             TOLUENE                      0.0
                             P-XYLENE                     0.87500
                             M-XYLENE                     0.0
                             O-XYLENE                     0.13900
                             METHANOL                     0.0
                             WATER                        0.0
                             METHANE                      0.0
                             N2                           0.0
                             H2                           0.0
                             CO                           0.0
                             CO2                          0.0
                             NAPTH                        0.0


                          ***  RESULTS  ***
```

```
 HEAT DUTY             BTU/HR                              -24.948

 COMPONENT = BENZENE
   STREAM     SUBSTREAM    SPLIT FRACTION
   S-217      MIXED                 1.00000

 COMPONENT = TOLUENE
   STREAM     SUBSTREAM    SPLIT FRACTION
   S-217      MIXED                 1.00000

 COMPONENT = P-XYLENE
   STREAM     SUBSTREAM    SPLIT FRACTION
   S-216      MIXED                 0.87500
   S-217      MIXED                 0.12500

 COMPONENT = M-XYLENE
   STREAM     SUBSTREAM    SPLIT FRACTION
   S-217      MIXED                 1.00000

 COMPONENT = O-XYLENE
   STREAM     SUBSTREAM    SPLIT FRACTION
   S-216      MIXED                 0.13900
   S-217      MIXED                 0.86100

 COMPONENT = NAPTH
   STREAM     SUBSTREAM    SPLIT FRACTION
   S-217      MIXED                 1.00000

BLOCK:  D-301    MODEL: FLASH3
------------------------------
  INLET STREAM:          S-307
  OUTLET VAPOR STREAM:   S-308
  FIRST LIQUID OUTLET:   S-310
  SECOND LIQUID OUTLET:  S-309
  PROPERTY OPTION SET:   NRTL      RENON (NRTL) / IDEAL GAS

                    ***  MASS AND ENERGY BALANCE  ***
                                  IN              OUT        RELATIVE DIFF.
   TOTAL BALANCE
      MOLE(LBMOL/HR)           323.060         323.060        0.175953E-15
      MASS(LB/HR   )           16728.9         16728.9        0.764455E-07
      ENTHALPY(BTU/HR  )     -0.219006E+08   -0.219006E+08    0.276890E-06

                    ***  CO2 EQUIVALENT SUMMARY ***
   FEED STREAMS CO2E            0.00000      LB/HR
   PRODUCT STREAMS CO2E         0.00000      LB/HR
   NET STREAMS CO2E PRODUCTION  0.00000      LB/HR
   UTILITIES CO2E PRODUCTION    0.00000      LB/HR
   TOTAL CO2E PRODUCTION        0.00000      LB/HR

                        ***  INPUT DATA  ***
  THREE  PHASE  PQ  FLASH
  PRESSURE DROP         PSI                               15.0000
  SPECIFIED HEAT DUTY   BTU/HR                             0.0
  MAXIMUM NO. ITERATIONS                                  30
  CONVERGENCE TOLERANCE                                    0.000100000
  KEY COMPONENT:          BENZENE
```

```
   KEY LIQUID STREAM:      S-309

                        ***  RESULTS  ***
   OUTLET TEMPERATURE    F                                    180.51
   OUTLET PRESSURE       PSIA                                 29.000
   VAPOR FRACTION                                             0.0000
   1ST LIQUID/TOTAL LIQUID                                    0.57383

   V-L1-L2 PHASE EQUILIBRIUM :

      COMP           F(I)      X1(I)      X2(I)      Y(I)       K1(I)      K2(I)
      BENZENE       0.105E-04 0.221E-06 0.244E-04 0.181E-04  62.2       0.562
      TOLUENE       0.255     0.486E-02 0.592     0.172      25.8       0.212
      P-XYLENE      0.140     0.661E-03 0.328     0.402E-01  42.9       0.864E-
01
      M-XYLENE      0.259E-08 0.298E-10 0.604E-08 0.838E-09  19.8       0.977E-
01
      O-XYLENE      0.425E-10 0.190E-11 0.971E-10 0.822E-11  3.04      0.595E-
01
      METHANOL      0.178     0.260     0.681E-01 0.486      1.35       5.15
      WATER         0.426     0.734     0.118E-01 0.302      0.282      17.5

 BLOCK:  F-101    MODEL: RSTOIC
 ------------------------------
   INLET STREAMS:         S-404       S-406
   OUTLET STREAM:         S-407
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

                        ***  MASS AND ENERGY BALANCE  ***
                                IN             OUT         GENERATION    RELATIVE
DIFF.
   TOTAL BALANCE
   MOLE(LBMOL/HR)          75225.9       74830.8      -395.154     -0.386886E-
15
   MASS(LB/HR   )        0.209780E+07  0.209780E+07                -0.221976E-
15
   ENTHALPY(BTU/HR  )   -0.460696E+08 -0.460696E+08                 0.323449E-
15

                        ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E            0.164348E+07  LB/HR
    PRODUCT STREAMS CO2E          333464.      LB/HR
    NET STREAMS CO2E PRODUCTION -0.131001E+07  LB/HR
    UTILITIES CO2E PRODUCTION     0.00000      LB/HR
    TOTAL CO2E PRODUCTION       -0.131001E+07  LB/HR

                        ***  INPUT DATA  ***
   STOICHIOMETRY MATRIX:

    REACTION #   1:
     SUBSTREAM MIXED   :
     WATER      2.00    METHANE   -1.00    CO2         1.00    O2         -2.00

    REACTION #   2:
     SUBSTREAM MIXED   :
     WATER      2.00    H2        -2.00    O2        -1.00
```

```
REACTION CONVERSION SPECS: NUMBER=    2
  REACTION #   1:
  SUBSTREAM:MIXED    KEY COMP:METHANE  CONV FRAC: 0.9000
  REACTION #   2:
  SUBSTREAM:MIXED    KEY COMP:H2       CONV FRAC: 0.9000



TWO    PHASE  PQ  FLASH
PRESSURE DROP         PSI                               7.00000
SPECIFIED HEAT DUTY   BTU/HR                            0.0
MAXIMUM NO. ITERATIONS                                 30
CONVERGENCE TOLERANCE                                   0.100000-05
SIMULTANEOUS REACTIONS
GENERATE COMBUSTION REACTIONS FOR FEED SPECIES        NO

                        ***  RESULTS  ***
OUTLET TEMPERATURE    F                                  2449.7
OUTLET PRESSURE       PSIA                               37.088
VAPOR FRACTION                                           1.0000



REACTION EXTENTS:

   REACTION          REACTION
   NUMBER            EXTENT
                     LBMOL/HR
   1                  3668.9
   2                  395.15

V-L PHASE EQUILIBRIUM :

   COMP             F(I)           X(I)           Y(I)            K(I)
   BENZENE         0.10772E-03    0.10772E-03    0.10772E-03     MISSING
   TOLUENE         0.14568E-05    0.14568E-05    0.14568E-05     MISSING
   P-XYLENE        0.13034E-08    0.13034E-08    0.13034E-08     MISSING
   M-XYLENE        0.11831E-08    0.11831E-08    0.11831E-08     MISSING
   O-XYLENE        0.88305E-09    0.88305E-09    0.88305E-09     MISSING
   WATER           0.10862        0.10862        0.10862         MISSING
   METHANE         0.54477E-02    0.54477E-02    0.54477E-02     MISSING
   N2              0.73987        0.73987        0.73987         MISSING
   H2              0.11735E-02    0.11735E-02    0.11735E-02     MISSING
   CO              0.69848E-04    0.69848E-04    0.69848E-04     MISSING
   CO2             0.51610E-01    0.51610E-01    0.51610E-01     MISSING
   NAPTH           0.76379E-08    0.76379E-08    0.76379E-08     MISSING
   O2              0.93104E-01    0.93104E-01    0.93104E-01     MISSING

BLOCK:  H-101    MODEL: HEATER
------------------------------
  INLET STREAM:           S-109
  INLET HEAT STREAM:      Q-101
  OUTLET STREAM:          S-110
  PROPERTY OPTION SET:    SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE
```

```
                    ***  MASS AND ENERGY BALANCE  ***
                                  IN              OUT        RELATIVE DIFF.
 TOTAL BALANCE
    MOLE(LBMOL/HR)            156450.        156450.         0.00000
    MASS(LB/HR   )          0.242839E+07    0.242839E+07     0.00000
    ENTHALPY(BTU/HR  )      -0.310148E+10   -0.310148E+10    0.153745E-15

                    ***  CO2 EQUIVALENT SUMMARY ***
 FEED STREAMS CO2E            0.517279E+08  LB/HR
 PRODUCT STREAMS CO2E         0.517279E+08  LB/HR
 NET STREAMS CO2E PRODUCTION   0.00000      LB/HR
 UTILITIES CO2E PRODUCTION     0.00000      LB/HR
 TOTAL CO2E PRODUCTION         0.00000      LB/HR

                        ***  INPUT DATA  ***
TWO    PHASE  PQ  FLASH
PRESSURE DROP                           PSI                           16.0000
DUTY FROM INLET HEAT STREAM(S)          BTU/HR                         0.189962+10
MAXIMUM NO. ITERATIONS                                                30
CONVERGENCE TOLERANCE                                                  0.100000-05



                         ***  RESULTS  ***
OUTLET TEMPERATURE    F                                         1172.0
OUTLET PRESSURE       PSIA                                      75.000
OUTLET VAPOR FRACTION                                           1.0000



V-L PHASE EQUILIBRIUM :

   COMP              F(I)           X(I)           Y(I)           K(I)
   BENZENE         0.11777E-02    0.11777E-02    0.11777E-02     16.164
   TOLUENE         0.15927E-04    0.15927E-04    0.15927E-04     40.878
   P-XYLENE        0.14250E-07    0.14250E-07    0.14250E-07     4.5324
   M-XYLENE        0.12935E-07    0.12935E-07    0.12935E-07     MISSING
   O-XYLENE        0.96541E-08    0.96541E-08    0.96541E-08     MISSING
   METHANE         0.82025        0.82025        0.82025         MISSING
   N2              0.11824E-01    0.11824E-01    0.11824E-01     MISSING
   H2              0.12829        0.12829        0.12829         MISSING
   CO              0.76363E-03    0.76363E-03    0.76363E-03     MISSING
   CO2             0.37674E-01    0.37674E-01    0.37674E-01     MISSING
   NAPTH           0.83503E-07    0.83503E-07    0.83503E-07     MISSING
BLOCK:  H-102    MODEL: HEATER
------------------------------
  INLET STREAM:           S-110
  OUTLET STREAM:          S-111
  OUTLET HEAT STREAM:     Q-102
  PROPERTY OPTION SET:    SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

                    ***  MASS AND ENERGY BALANCE  ***
                                  IN              OUT        RELATIVE DIFF.
 TOTAL BALANCE
    MOLE(LBMOL/HR)            156450.        156450.         0.00000
    MASS(LB/HR   )          0.242839E+07    0.242839E+07     0.00000
```

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   ENTHALPY(BTU/HR  )      -0.310148E+10   -0.310148E+10    0.153745E-15

                  ***  CO2 EQUIVALENT SUMMARY ***
 FEED STREAMS CO2E            0.517279E+08  LB/HR
 PRODUCT STREAMS CO2E         0.517279E+08  LB/HR
 NET STREAMS CO2E PRODUCTION   0.00000      LB/HR
 UTILITIES CO2E PRODUCTION     0.00000      LB/HR
 TOTAL CO2E PRODUCTION         0.00000      LB/HR

                      ***  INPUT DATA  ***
TWO    PHASE  TP  FLASH
SPECIFIED TEMPERATURE               F                      1,440.00
PRESSURE DROP                       PSI                       16.0000
MAXIMUM NO. ITERATIONS                                        30
CONVERGENCE TOLERANCE                                          0.100000-05



                       ***  RESULTS  ***
OUTLET TEMPERATURE    F                                    1440.0
OUTLET PRESSURE       PSIA                                 59.000
HEAT DUTY             BTU/HR                              0.65692E+09
OUTLET VAPOR FRACTION                                      1.0000



V-L PHASE EQUILIBRIUM :

   COMP              F(I)          X(I)          Y(I)          K(I)
   BENZENE          0.11777E-02    0.11777E-02    0.11777E-02     MISSING
   TOLUENE          0.15927E-04    0.15927E-04    0.15927E-04     MISSING
   P-XYLENE         0.14250E-07    0.14250E-07    0.14250E-07     MISSING
   M-XYLENE         0.12935E-07    0.12935E-07    0.12935E-07     MISSING
   O-XYLENE         0.96541E-08    0.96541E-08    0.96541E-08     MISSING
   METHANE          0.82025        0.82025        0.82025         MISSING
   N2               0.11824E-01    0.11824E-01    0.11824E-01     MISSING
   H2               0.12829        0.12829        0.12829         MISSING
   CO               0.76363E-03    0.76363E-03    0.76363E-03     MISSING
   CO2              0.37674E-01    0.37674E-01    0.37674E-01     MISSING
   NAPTH            0.83503E-07    0.83503E-07    0.83503E-07     MISSING

BLOCK:  H-103    MODEL: HEATER
------------------------------
  INLET STREAM:           S-112
  OUTLET STREAM:          S-113
  OUTLET HEAT STREAM:     Q-101
  PROPERTY OPTION SET:    SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

                  ***  MASS AND ENERGY BALANCE  ***
                                IN              OUT         RELATIVE DIFF.
 TOTAL BALANCE
   MOLE(LBMOL/HR)            151521.         151521.          0.00000
   MASS(LB/HR   )          0.242839E+07    0.242839E+07     0.00000
   ENTHALPY(BTU/HR  )      -0.244457E+10   -0.244457E+10   -0.390120E-15

                  ***  CO2 EQUIVALENT SUMMARY ***
 FEED STREAMS CO2E            0.469622E+08  LB/HR
```

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 PRODUCT STREAMS CO2E         0.469622E+08  LB/HR
 NET STREAMS CO2E PRODUCTION   0.00000      LB/HR
 UTILITIES CO2E PRODUCTION     0.00000      LB/HR
 TOTAL CO2E PRODUCTION         0.00000      LB/HR

                      ***  INPUT DATA  ***
TWO    PHASE  TP  FLASH
SPECIFIED TEMPERATURE               F                       250.000
PRESSURE DROP                       PSI                      16.0000
MAXIMUM NO. ITERATIONS                                       30
CONVERGENCE TOLERANCE                                         0.100000-05



                       ***  RESULTS  ***
OUTLET TEMPERATURE    F                               250.00
OUTLET PRESSURE       PSIA                            27.000
HEAT DUTY             BTU/HR                         -0.18996E+10
OUTLET VAPOR FRACTION                                 1.0000



V-L PHASE EQUILIBRIUM :

   COMP              F(I)          X(I)           Y(I)           K(I)
   BENZENE         0.12813E-01    0.84298E-01    0.12813E-01     1.6271
   TOLUENE         0.59137E-03    0.81510E-02    0.59137E-03    0.77666
   P-XYLENE        0.39424E-05    0.11112E-03    0.39424E-05    0.37980
   M-XYLENE        0.39424E-05    0.11483E-03    0.39424E-05    0.36754
   O-XYLENE        0.39424E-05    0.13978E-03    0.39424E-05    0.30192
   METHANE         0.76878        0.26604E-01    0.76878         309.34
   N2              0.12208E-01    0.16478E-03    0.12208E-01     793.14
   H2              0.16558        0.13531E-02    0.16558         1310.0
   CO              0.98561E-03    0.14111E-04    0.98561E-03     747.72
   CO2             0.36468E-01    0.39818E-02    0.36468E-01     98.041
   NAPTH            0.25626E-02    0.87507        0.25626E-02    0.31349E-
01

BLOCK:  H-104    MODEL: HEATER
------------------------------
  INLET STREAM:           S-120
  INLET HEAT STREAM:      Q-103
  OUTLET STREAM:          S-121
  PROPERTY OPTION SET:    SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

                  ***  MASS AND ENERGY BALANCE  ***
                               IN              OUT        RELATIVE DIFF.
 TOTAL BALANCE
    MOLE(LBMOL/HR)           151521.         151521.         0.00000
    MASS(LB/HR   )         0.242839E+07    0.242839E+07     0.00000
    ENTHALPY(BTU/HR  )    -0.401607E+10   -0.401607E+10     0.00000

                  ***  CO2 EQUIVALENT SUMMARY ***
 FEED STREAMS CO2E            0.469622E+08  LB/HR
 PRODUCT STREAMS CO2E         0.469622E+08  LB/HR
 NET STREAMS CO2E PRODUCTION   0.00000      LB/HR
 UTILITIES CO2E PRODUCTION     0.00000      LB/HR
```

TOTAL CO2E PRODUCTION 0.00000 LB/HR

*** INPUT DATA ***

TWO PHASE PQ FLASH

PRESSURE DROP	PSI	16.0000
DUTY FROM INLET HEAT STREAM(S)	BTU/HR	-0.153351+08
MAXIMUM NO. ITERATIONS		30
CONVERGENCE TOLERANCE		0.100000-05

*** RESULTS ***

OUTLET TEMPERATURE	F	462.52
OUTLET PRESSURE	PSIA	74.000
OUTLET VAPOR FRACTION		1.0000

V-L PHASE EQUILIBRIUM :

COMP	F(I)	X(I)	Y(I)	K(I)
BENZENE	0.12813E-01	0.10624	0.12813E-01	3.6645
TOLUENE	0.59137E-03	0.10766E-01	0.59137E-03	2.1791
P-XYLENE	0.39424E-05	0.14548E-03	0.39424E-05	1.1509
M-XYLENE	0.39424E-05	0.14945E-03	0.39424E-05	1.1560
O-XYLENE	0.39424E-05	0.17709E-03	0.39424E-05	1.1054
METHANE	0.76878	0.27165E-01	0.76878	61.846
N2	0.12208E-01	0.17058E-03	0.12208E-01	97.019
H2	0.16558	0.13314E-02	0.16558	132.01
CO	0.98561E-03	0.14808E-04	0.98561E-03	94.148
CO2	0.36468E-01	0.41845E-02	0.36468E-01	42.225
NAPTH	0.25626E-02	0.84966	0.25626E-02	0.35412

BLOCK: H-105 MODEL: HEATER

INLET STREAM: S-121
OUTLET STREAM: S-122
PROPERTY OPTION SET: SRK SOAVE-REDLICH-KWONG EQUATION OF STATE

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(LBMOL/HR)	151521.	151521.	0.00000
MASS(LB/HR)	0.242839E+07	0.242839E+07	0.00000
ENTHALPY(BTU/HR)	-0.401607E+10	-0.454727E+10	0.116817

*** CO2 EQUIVALENT SUMMARY ***

FEED STREAMS CO2E	0.469622E+08	LB/HR
PRODUCT STREAMS CO2E	0.469622E+08	LB/HR
NET STREAMS CO2E PRODUCTION	0.00000	LB/HR
UTILITIES CO2E PRODUCTION	0.00000	LB/HR
TOTAL CO2E PRODUCTION	0.00000	LB/HR

*** INPUT DATA ***

TWO PHASE TP FLASH

SPECIFIED TEMPERATURE	F	110.000
PRESSURE DROP	PSI	15.0000

```
MAXIMUM NO. ITERATIONS                                               30
CONVERGENCE TOLERANCE                                                 0.100000-05



                       ***  RESULTS  ***
OUTLET TEMPERATURE    F                                         110.00
OUTLET PRESSURE       PSIA                                      59.000
HEAT DUTY             BTU/HR                                  -0.53120E+09
OUTLET VAPOR FRACTION                                            0.99714



V-L PHASE EQUILIBRIUM :

   COMP              F(I)           X(I)           Y(I)           K(I)
   BENZENE          0.12813E-01    0.16643        0.12372E-01    0.74336E-
01
   TOLUENE          0.59137E-03    0.20273E-01    0.53483E-03    0.26382E-
01
   P-XYLENE         0.39424E-05    0.32528E-03    0.30194E-05    0.92826E-
02
   M-XYLENE         0.39424E-05    0.33975E-03    0.29779E-05    0.87648E-
02
   O-XYLENE         0.39424E-05    0.40643E-03    0.27863E-05    0.68556E-
02
   METHANE         0.76878        0.68298E-02    0.77097         112.88
   N2              0.12208E-01    0.31161E-04    0.12243E-01     392.91
   H2              0.16558        0.18866E-03    0.16606         880.17
   CO              0.98561E-03    0.27683E-05    0.98843E-03     357.05
   CO2             0.36468E-01    0.19097E-02    0.36567E-01     19.148
   NAPTH            0.25626E-02    0.80326        0.26269E-03    0.32702E-
03

 BLOCK:  H-106    MODEL: HEATER
 ------------------------------
   INLET STREAM:          S-122
   OUTLET STREAM:         S-123
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

                    ***  MASS AND ENERGY BALANCE  ***
                                 IN              OUT        RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(LBMOL/HR)          151521.         151521.         0.00000
       MASS(LB/HR   )         0.242839E+07    0.242839E+07     0.00000
       ENTHALPY(BTU/HR  )    -0.454727E+10   -0.475314E+10    0.433118E-01

                    ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E           0.469622E+08  LB/HR
    PRODUCT STREAMS CO2E        0.469622E+08  LB/HR
    NET STREAMS CO2E PRODUCTION   0.00000      LB/HR
    UTILITIES CO2E PRODUCTION     0.00000      LB/HR
    TOTAL CO2E PRODUCTION         0.00000      LB/HR

                        ***  INPUT DATA  ***
   TWO    PHASE  TP  FLASH
   SPECIFIED TEMPERATURE               F                          -30.0000
```

PRESSURE DROP	PSI	15.0000
MAXIMUM NO. ITERATIONS		30
CONVERGENCE TOLERANCE		0.100000-05

*** RESULTS ***

OUTLET TEMPERATURE	F	-30.000
OUTLET PRESSURE	PSIA	44.000
HEAT DUTY	BTU/HR	-0.20587E+09
OUTLET VAPOR FRACTION		0.98490

V-L PHASE EQUILIBRIUM :

COMP	F(I)	X(I)	Y(I)	K(I)
BENZENE	0.12813E-01	0.77643	0.11022E-02	0.14196E-02
TOLUENE	0.59137E-03	0.38191E-01	0.14738E-04	0.38590E-03
P-XYLENE	0.39424E-05	0.26015E-03	0.13322E-07	0.51211E-04
M-XYLENE	0.39424E-05	0.26023E-03	0.12103E-07	0.46509E-04
O-XYLENE	0.39424E-05	0.26043E-03	0.90456E-08	0.34734E-04
METHANE	0.76878	0.93412E-02	0.78042	83.546
N2	0.12208E-01	0.29424E-04	0.12395E-01	421.26
H2	0.16558	0.10356E-03	0.16812	1623.3
CO	0.98561E-03	0.28347E-05	0.10007E-02	353.01
CO2	0.36468E-01	0.54702E-02	0.36943E-01	6.7535
NAPTH	0.25626E-02	0.16965	0.80849E-07	0.47655E-06

BLOCK: H-107 MODEL: HEATER

INLET STREAM:	S-124	
OUTLET STREAM:	S-201	
OUTLET HEAT STREAM:	Q-103	
PROPERTY OPTION SET:	SRK	SOAVE-REDLICH-KWONG EQUATION OF STATE

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(LBMOL/HR)	2209.22	2209.22	0.00000
MASS(LB/HR)	192156.	192156.	0.151459E-15
ENTHALPY(BTU/HR)	0.439006E+08	0.439017E+08	-0.250905E-04

*** CO2 EQUIVALENT SUMMARY ***

FEED STREAMS CO2E	5695.48	LB/HR
PRODUCT STREAMS CO2E	5695.48	LB/HR
NET STREAMS CO2E PRODUCTION	0.00000	LB/HR
UTILITIES CO2E PRODUCTION	0.00000	LB/HR
TOTAL CO2E PRODUCTION	0.00000	LB/HR

*** INPUT DATA ***

TWO PHASE TP FLASH

SPECIFIED TEMPERATURE	F	170.000
PRESSURE DROP	PSI	15.0000
MAXIMUM NO. ITERATIONS		30
CONVERGENCE TOLERANCE		0.100000-05

*** RESULTS ***

OUTLET TEMPERATURE	F	170.00
OUTLET PRESSURE	PSIA	13.000
HEAT DUTY	BTU/HR	0.15336E+08
OUTLET VAPOR FRACTION		0.47137E-01

V-L PHASE EQUILIBRIUM :

COMP	F(I)	X(I)	Y(I)	K(I)
BENZENE	0.77454	0.77399	0.78553	1.0149
TOLUENE	0.39150E-01	0.40129E-01	0.19339E-01	0.48192
P-XYLENE	0.26913E-03	0.28023E-03	0.44781E-04	0.15980
M-XYLENE	0.26925E-03	0.28044E-03	0.43081E-04	0.15362
O-XYLENE	0.26954E-03	0.28112E-03	0.35448E-04	0.12609
METHANE	0.60282E-02	0.23664E-03	0.12310	520.22
N2	0.18713E-04	0.27710E-06	0.39139E-03	1412.5
H2	0.64952E-04	0.50198E-06	0.13678E-02	2724.8
CO	0.18071E-05	0.29160E-07	0.37747E-04	1294.5
CO2	0.36425E-02	0.44256E-03	0.68329E-01	154.40
NAPTH	0.17575	0.18436	0.17779E-02	0.96437E-02

BLOCK: H-201 MODEL: HEATER

INLET STREAM:	S-213	
OUTLET STREAM:	S-214	
PROPERTY OPTION SET:	SRK	SOAVE-REDLICH-KWONG EQUATION OF STATE

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(LBMOL/HR)	48.6000	48.6000	0.00000
MASS(LB/HR)	5120.08	5120.08	0.00000
ENTHALPY(BTU/HR)	-7488.18	-405392.	0.981529

*** CO2 EQUIVALENT SUMMARY ***

FEED STREAMS CO2E	0.00000	LB/HR
PRODUCT STREAMS CO2E	0.00000	LB/HR
NET STREAMS CO2E PRODUCTION	0.00000	LB/HR
UTILITIES CO2E PRODUCTION	0.00000	LB/HR
TOTAL CO2E PRODUCTION	0.00000	LB/HR

*** INPUT DATA ***

TWO PHASE TP FLASH

SPECIFIED TEMPERATURE	F	110.000
PRESSURE DROP	PSI	16.0000
MAXIMUM NO. ITERATIONS		30

```
  CONVERGENCE TOLERANCE                                           0.100000-05


                       ***  RESULTS  ***
  OUTLET TEMPERATURE    F                                    110.00
  OUTLET PRESSURE       PSIA                                 30.696
  HEAT DUTY             BTU/HR                              -0.39790E+06
  OUTLET VAPOR FRACTION                                      0.0000


  V-L PHASE EQUILIBRIUM :

     COMP              F(I)           X(I)           Y(I)           K(I)
     BENZENE          0.85964E-08    0.85964E-08    0.68691E-07    0.14609
     TOLUENE           0.58929E-01    0.58929E-01    0.15396        0.47766E-
01
     P-XYLENE          0.91718        0.91718        0.82740        0.16493E-
01
     M-XYLENE          0.11902E-01    0.11902E-01    0.10298E-01    0.15819E-
01
     O-XYLENE          0.11508E-01    0.11508E-01    0.83191E-02    0.13216E-
01
     NAPTH             0.48003E-03    0.48003E-03    0.22682E-04    0.86387E-
03

 BLOCK:  H-202    MODEL: HEATER
 ------------------------------
  INLET STREAM:           S-218
  OUTLET STREAM:          S-219
  PROPERTY OPTION SET:    SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

                  ***  MASS AND ENERGY BALANCE  ***
                                  IN              OUT         RELATIVE DIFF.
   TOTAL BALANCE
      MOLE(LBMOL/HR)            389.459         389.459         0.00000
      MASS(LB/HR   )            49891.6         49891.6         0.00000
      ENTHALPY(BTU/HR  )       0.236131E+08    0.166490E+08    0.294926

                  ***  CO2 EQUIVALENT SUMMARY ***
   FEED STREAMS CO2E             0.00000      LB/HR
   PRODUCT STREAMS CO2E          0.00000      LB/HR
   NET STREAMS CO2E PRODUCTION   0.00000      LB/HR
   UTILITIES CO2E PRODUCTION     0.00000      LB/HR
   TOTAL CO2E PRODUCTION         0.00000      LB/HR

                      ***  INPUT DATA  ***
  TWO    PHASE  TP  FLASH
  SPECIFIED TEMPERATURE               F                        110.000
  PRESSURE DROP                       PSI                       16.0000
  MAXIMUM NO. ITERATIONS                                        30
  CONVERGENCE TOLERANCE                                           0.100000-05


                       ***  RESULTS  ***
```

```
OUTLET TEMPERATURE    F                                     110.00
OUTLET PRESSURE       PSIA                                  34.646
HEAT DUTY             BTU/HR                               -0.69641E+07
OUTLET VAPOR FRACTION                                       0.0000


V-L PHASE EQUILIBRIUM :

   COMP             F(I)          X(I)          Y(I)          K(I)
   BENZENE         0.72931E-13   0.72931E-13   0.12184E-10   0.12030
   TOLUENE         0.12465E-04   0.12465E-04   0.77231E-03   0.44617E-
01
   P-XYLENE        0.29632E-02   0.29632E-02   0.72804E-01   0.17692E-
01
   M-XYLENE        0.42152E-04   0.42152E-04   0.97623E-03   0.16677E-
01
   O-XYLENE        0.92878E-04   0.92878E-04   0.16687E-02   0.12938E-
01
   NAPTH           0.99689       0.99689       0.92378       0.66727E-
03

BLOCK:  H-203    MODEL: HEATER
------------------------------
  INLET STREAM:          S-216
  OUTLET STREAM:         S-220
  OUTLET HEAT STREAM:    Q-204
  PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

                  ***  MASS AND ENERGY BALANCE  ***
                                 IN              OUT        RELATIVE DIFF.
  TOTAL BALANCE
     MOLE(LBMOL/HR)          39.0809         39.0809         0.00000
     MASS(LB/HR   )          4149.11         4149.11         0.00000
     ENTHALPY(BTU/HR  )     -557935.        -557935.         0.00000

                  ***  CO2 EQUIVALENT SUMMARY ***
  FEED STREAMS CO2E            0.00000      LB/HR
  PRODUCT STREAMS CO2E         0.00000      LB/HR
  NET STREAMS CO2E PRODUCTION  0.00000      LB/HR
  UTILITIES CO2E PRODUCTION    0.00000      LB/HR
  TOTAL CO2E PRODUCTION        0.00000      LB/HR

                      ***  INPUT DATA  ***
TWO    PHASE  TP  FLASH
SPECIFIED TEMPERATURE               F                       100.0000
PRESSURE DROP                       PSI                       7.00000
MAXIMUM NO. ITERATIONS                                       30
CONVERGENCE TOLERANCE                                         0.100000-05



                       ***  RESULTS  ***
OUTLET TEMPERATURE    F                                     100.00
OUTLET PRESSURE       PSIA                                  7.6959
HEAT DUTY             BTU/HR                               0.17756E+06
OUTLET VAPOR FRACTION                                       0.0000
```

V-L PHASE EQUILIBRIUM :

COMP	F(I)	X(I)	Y(I)	K(I)
P-XYLENE	0.99801	0.99801	0.99841	0.43367E-01
O-XYLENE	0.19893E-02	0.19893E-02	0.15910E-02	0.34671E-01

BLOCK: H-301   MODEL: HEATER

INLET STREAM:	S-302
OUTLET STREAM:	S-303
OUTLET HEAT STREAM:	Q-301
PROPERTY OPTION SET:	SRK SOAVE-REDLICH-KWONG EQUATION OF STATE

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(LBMOL/HR)	323.060	323.060	0.00000
MASS(LB/HR)	16728.9	16728.9	0.00000
ENTHALPY(BTU/HR)	-0.202687E+08	-0.202687E+08	0.00000

*** CO2 EQUIVALENT SUMMARY ***

FEED STREAMS CO2E	0.00000	LB/HR
PRODUCT STREAMS CO2E	0.00000	LB/HR
NET STREAMS CO2E PRODUCTION	0.00000	LB/HR
UTILITIES CO2E PRODUCTION	0.00000	LB/HR
TOTAL CO2E PRODUCTION	0.00000	LB/HR

*** INPUT DATA ***

TWO   PHASE TP FLASH

SPECIFIED TEMPERATURE	F	1,105.00
PRESSURE DROP	PSI	7.00000
MAXIMUM NO. ITERATIONS		30
CONVERGENCE TOLERANCE		0.100000-05

*** RESULTS ***

OUTLET TEMPERATURE	F	1105.0
OUTLET PRESSURE	PSIA	45.000
HEAT DUTY	BTU/HR	0.12810E+08
OUTLET VAPOR FRACTION		1.0000

V-L PHASE EQUILIBRIUM :

COMP	F(I)	X(I)	Y(I)	K(I)
BENZENE	0.10527E-04	0.10527E-04	0.10527E-04	MISSING
TOLUENE	0.39500	0.39500	0.39500	MISSING
P-XYLENE	0.25827E-03	0.25827E-03	0.25827E-03	MISSING
M-XYLENE	0.25907E-08	0.25907E-08	0.25907E-08	MISSING
O-XYLENE	0.42460E-10	0.42460E-10	0.42460E-10	MISSING

```
    METHANOL          0.31828         0.31828         0.31828          MISSING
    WATER             0.28645         0.28645         0.28645          MISSING

BLOCK:  H-302    MODEL: HEATER
------------------------------
  INLET STREAM:             S-304
  INLET HEAT STREAM:        Q-301
  OUTLET STREAM:            S-305
  PROPERTY OPTION SET:      SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

                     ***  MASS AND ENERGY BALANCE  ***
                                   IN               OUT        RELATIVE DIFF.
   TOTAL BALANCE
      MOLE(LBMOL/HR)            323.060         323.060         0.00000
      MASS(LB/HR   )            16728.9         16728.9         0.00000
      ENTHALPY(BTU/HR  )      -0.202687E+08   -0.202687E+08     0.00000

                     ***  CO2 EQUIVALENT SUMMARY ***
   FEED STREAMS CO2E             0.00000      LB/HR
   PRODUCT STREAMS CO2E          0.00000      LB/HR
   NET STREAMS CO2E PRODUCTION   0.00000      LB/HR
   UTILITIES CO2E PRODUCTION     0.00000      LB/HR
   TOTAL CO2E PRODUCTION         0.00000      LB/HR

                         ***  INPUT DATA  ***
  TWO    PHASE  PQ  FLASH
  PRESSURE DROP                         PSI                          7.00000
  DUTY FROM INLET HEAT STREAM(S)        BTU/HR                      -0.128101+08
  MAXIMUM NO. ITERATIONS                                            30
  CONVERGENCE TOLERANCE                                              0.100000-05



                          ***  RESULTS  ***
  OUTLET TEMPERATURE    F                                       178.31
  OUTLET PRESSURE       PSIA                                    21.000
  OUTLET VAPOR FRACTION                                         0.22623



  V-L PHASE EQUILIBRIUM :

    COMP               F(I)            X(I)            Y(I)            K(I)
    BENZENE           0.10527E-04     0.10833E-04     0.94798E-05     0.87512
    TOLUENE           0.25517         0.30043         0.10037         0.33408
    P-XYLENE          0.14009         0.17335         0.26341E-01     0.15195
    M-XYLENE          0.25907E-08     0.32123E-08     0.46465E-09     0.14465
    O-XYLENE          0.42460E-10     0.53117E-10     0.60095E-11     0.11314
    METHANOL          0.17845         0.16274         0.23215          1.4265
    WATER             0.42628         0.36347         0.64113          1.7639

BLOCK:  H-303    MODEL: HEATER
------------------------------
  INLET STREAM:             S-305
  OUTLET STREAM:            S-306
  PROPERTY OPTION SET:      SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE
```

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(LBMOL/HR)	323.060	323.060	0.00000
MASS(LB/HR)	16728.9	16728.9	0.00000
ENTHALPY(BTU/HR)	-0.202687E+08	-0.219039E+08	0.746524E-01

*** CO2 EQUIVALENT SUMMARY ***

FEED STREAMS CO2E	0.00000	LB/HR
PRODUCT STREAMS CO2E	0.00000	LB/HR
NET STREAMS CO2E PRODUCTION	0.00000	LB/HR
UTILITIES CO2E PRODUCTION	0.00000	LB/HR
TOTAL CO2E PRODUCTION	0.00000	LB/HR

*** INPUT DATA ***

TWO PHASE PV FLASH

PRESSURE DROP	PSI	15.0000
VAPOR FRACTION		0.0
MAXIMUM NO. ITERATIONS		30
CONVERGENCE TOLERANCE		0.100000-05

*** RESULTS ***

OUTLET TEMPERATURE	F	116.79
OUTLET PRESSURE	PSIA	6.0000
HEAT DUTY	BTU/HR	-0.16352E+07
OUTLET VAPOR FRACTION		0.0000

V-L PHASE EQUILIBRIUM :

COMP	F(I)	X(I)	Y(I)	K(I)
BENZENE	0.10527E-04	0.10527E-04	0.11519E-04	1.0943
TOLUENE	0.25517	0.25517	0.97450E-01	0.38190
P-XYLENE	0.14009	0.14009	0.23085E-01	0.16479
M-XYLENE	0.25907E-08	0.25907E-08	0.39654E-09	0.15307
O-XYLENE	0.42460E-10	0.42460E-10	0.47141E-11	0.11102
METHANOL	0.17845	0.17845	0.21494	1.2045
WATER	0.42628	0.42628	0.66451	1.5589

BLOCK: H-401 MODEL: HEATER

INLET STREAM:	S-407	
INLET HEAT STREAM:	Q-102	
OUTLET STREAM:	S-408	
PROPERTY OPTION SET:	SRK	SOAVE-REDLICH-KWONG EQUATION OF STATE

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(LBMOL/HR)	74830.8	74830.8	0.00000
MASS(LB/HR)	0.209780E+07	0.209780E+07	0.00000
ENTHALPY(BTU/HR)	-0.702986E+09	-0.702986E+09	-0.169576E-15

*** CO2 EQUIVALENT SUMMARY ***

```
 FEED STREAMS CO2E             333464.      LB/HR
 PRODUCT STREAMS CO2E          333464.      LB/HR
 NET STREAMS CO2E PRODUCTION   0.00000      LB/HR
 UTILITIES CO2E PRODUCTION     0.00000      LB/HR
 TOTAL CO2E PRODUCTION         0.00000      LB/HR

                      ***  INPUT DATA  ***
 TWO    PHASE  PQ  FLASH
 PRESSURE DROP                          PSI                        7.00000
 DUTY FROM INLET HEAT STREAM(S)         BTU/HR                    -0.656916+09
 MAXIMUM NO. ITERATIONS                                           30
 CONVERGENCE TOLERANCE                                             0.100000-05



                       ***  RESULTS  ***
 OUTLET TEMPERATURE    F                                       1459.3
 OUTLET PRESSURE       PSIA                                    30.088
 OUTLET VAPOR FRACTION                                         1.0000



 V-L PHASE EQUILIBRIUM :

    COMP            F(I)           X(I)           Y(I)           K(I)
    BENZENE         0.10772E-03    0.10772E-03    0.10772E-03    MISSING
    TOLUENE         0.14568E-05    0.14568E-05    0.14568E-05    MISSING
    P-XYLENE        0.13034E-08    0.13034E-08    0.13034E-08    MISSING
    M-XYLENE        0.11831E-08    0.11831E-08    0.11831E-08    MISSING
    O-XYLENE        0.88305E-09    0.88305E-09    0.88305E-09    MISSING
    WATER           0.10862        0.10862        0.10862        MISSING
    METHANE         0.54477E-02    0.54477E-02    0.54477E-02    MISSING
    N2              0.73987        0.73987        0.73987        MISSING
    H2              0.11735E-02    0.11735E-02    0.11735E-02    MISSING
    CO              0.69848E-04    0.69848E-04    0.69848E-04    MISSING
    CO2             0.51610E-01    0.51610E-01    0.51610E-01    MISSING
    NAPTH           0.76379E-08    0.76379E-08    0.76379E-08    MISSING
    O2              0.93104E-01    0.93104E-01    0.93104E-01    MISSING

BLOCK:  H-402    MODEL: HEATER
------------------------------
 INLET STREAM:           S-408
 INLET HEAT STREAM:      Q-104
 OUTLET STREAM:          S-409
 PROPERTY OPTION SET:    SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

                  ***  MASS AND ENERGY BALANCE  ***
                                 IN              OUT          RELATIVE DIFF.
 TOTAL BALANCE
    MOLE(LBMOL/HR)            74830.8         74830.8          0.00000
    MASS(LB/HR   )          0.209780E+07    0.209780E+07       0.00000
    ENTHALPY(BTU/HR  )     -0.750817E+09   -0.750817E+09       0.00000

                  ***  CO2 EQUIVALENT SUMMARY ***
 FEED STREAMS CO2E             333464.      LB/HR
 PRODUCT STREAMS CO2E          333464.      LB/HR
 NET STREAMS CO2E PRODUCTION   0.00000      LB/HR
```

```
 UTILITIES CO2E PRODUCTION     0.00000      LB/HR
 TOTAL CO2E PRODUCTION         0.00000      LB/HR

                      ***  INPUT DATA  ***
TWO    PHASE  PQ  FLASH
PRESSURE DROP                        PSI                        0.0
DUTY FROM INLET HEAT STREAM(S)       BTU/HR                    -0.478309+08
MAXIMUM NO. ITERATIONS                                         30
CONVERGENCE TOLERANCE                                           0.100000-05



                       ***  RESULTS  ***
OUTLET TEMPERATURE    F                                    1383.9
OUTLET PRESSURE       PSIA                                 30.088
OUTLET VAPOR FRACTION                                      1.0000



V-L PHASE EQUILIBRIUM :

   COMP              F(I)           X(I)           Y(I)           K(I)
   BENZENE          0.10772E-03    0.10772E-03    0.10772E-03     MISSING
   TOLUENE          0.14568E-05    0.14568E-05    0.14568E-05     MISSING
   P-XYLENE         0.13034E-08    0.13034E-08    0.13034E-08     MISSING
   M-XYLENE         0.11831E-08    0.11831E-08    0.11831E-08     MISSING
   O-XYLENE         0.88305E-09    0.88305E-09    0.88305E-09     MISSING
   WATER            0.10862        0.10862        0.10862         MISSING
   METHANE          0.54477E-02    0.54477E-02    0.54477E-02     MISSING
   N2               0.73987        0.73987        0.73987         MISSING
   H2               0.11735E-02    0.11735E-02    0.11735E-02     MISSING
   CO               0.69848E-04    0.69848E-04    0.69848E-04     MISSING
   CO2              0.51610E-01    0.51610E-01    0.51610E-01     MISSING
   NAPTH            0.76379E-08    0.76379E-08    0.76379E-08     MISSING
   O2               0.93104E-01    0.93104E-01    0.93104E-01     MISSING

BLOCK:  H-403    MODEL: HEATX
-----------------------------
  HOT SIDE:
  ---------
  INLET STREAM:             S-409
  OUTLET STREAM:            S-421
  PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE
  COLD SIDE:
  ----------
  INLET STREAM:             S-411
  OUTLET STREAM:            S-412
  PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

                    ***  MASS AND ENERGY BALANCE  ***
                                 IN              OUT        RELATIVE DIFF.
   TOTAL BALANCE
      MOLE(LBMOL/HR)          97830.8         97830.8         0.00000
      MASS(LB/HR   )         0.251215E+07    0.251215E+07     0.00000
      ENTHALPY(BTU/HR  )    -0.359267E+10   -0.359267E+10     0.00000

                    ***  CO2 EQUIVALENT SUMMARY ***
```

```
 FEED STREAMS CO2E              333464.      LB/HR
 PRODUCT STREAMS CO2E           333464.      LB/HR
 NET STREAMS CO2E PRODUCTION    0.00000      LB/HR
 UTILITIES CO2E PRODUCTION      0.00000      LB/HR
 TOTAL CO2E PRODUCTION          0.00000      LB/HR

                      ***  INPUT DATA  ***

FLASH SPECS FOR HOT SIDE:
TWO    PHASE      FLASH
MAXIMUM NO. ITERATIONS                                 30
CONVERGENCE TOLERANCE                                   0.100000-05

FLASH SPECS FOR COLD SIDE:
TWO    PHASE      FLASH
MAXIMUM NO. ITERATIONS                                 30
CONVERGENCE TOLERANCE                                   0.100000-05

FLOW DIRECTION AND SPECIFICATION:
  COUNTERCURRENT   HEAT EXCHANGER
  SPECIFIED COLD DEG. SUPERHEAT
  SPECIFIED VALUE               F                     100.0000
  LMTD CORRECTION FACTOR                                1.00000

PRESSURE SPECIFICATION:
  HOT  SIDE PRESSURE DROP        PSI                    0.0000
  COLD SIDE PRESSURE DROP        PSI                    0.0000

HEAT TRANSFER COEFFICIENT SPECIFICATION:
  OVERALL COEFFICIENT            BTU/HR-SQFT-R        150.0000

                      ***  OVERALL RESULTS  ***

STREAMS:
                --------------------------------------
                |                                    |
S-409     ----->|                HOT                 |-----> S-421
T=  1.3839D+03  |                                              |         T=
5.0093D+02
P=  3.0088D+01  |                                              |         P=
3.0088D+01
V=  1.0000D+00  |                                              |         V=
1.0000D+00
                |                                    |
S-412     <-----|                COLD                |<----- S-411
T=  5.4267D+02  |                                              |         T=
1.0636D+02
P=  4.0000D+02  |                                              |         P=
4.0000D+02
V=  1.0000D+00  |                                              |         V=
0.0000D+00
                --------------------------------------

DUTY AND AREA:
  CALCULATED HEAT DUTY           BTU/HR         528099053.0457
  CALCULATED (REQUIRED) AREA     SQFT                5967.4713
  ACTUAL EXCHANGER AREA          SQFT                5967.4713
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```
  PER CENT OVER-DESIGN                                          0.0000

 HEAT TRANSFER COEFFICIENT:
  AVERAGE COEFFICIENT (DIRTY)    BTU/HR-SQFT-R             150.0000
  UA (DIRTY)                     BTU/HR-R               895120.6991

 LOG-MEAN TEMPERATURE DIFFERENCE:
  LMTD CORRECTION FACTOR                                     1.0000
  LMTD (CORRECTED)               F                         589.9752
  NUMBER OF SHELLS IN SERIES                                  1

 PRESSURE DROP:
  HOTSIDE, TOTAL                 PSI                         0.0000
  COLDSIDE, TOTAL                PSI                         0.0000

HEATX COLD-TQCU H-403    TQCURV INLET
-------------------------------------
 PRESSURE PROFILE:      CONSTANT2
 PRESSURE DROP:         0.0        PSI
 PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE
```

DUTY BTU/HR	PRES PSIA	TEMP F	VFRAC
0.0	400.0000	542.6663	1.0000
2.2058+07	400.0000	442.6663	DEW>1.0000
2.5148+07	400.0000	442.6663	0.9909
5.0295+07	400.0000	442.6663	0.9165
7.5443+07	400.0000	442.6663	0.8421
1.0059+08	400.0000	442.6663	0.7677
1.2574+08	400.0000	442.6663	0.6933
1.5089+08	400.0000	442.6663	0.6190
1.7603+08	400.0000	442.6663	0.5446
2.0118+08	400.0000	442.6663	0.4702
2.2633+08	400.0000	442.6663	0.3958
2.5148+08	400.0000	442.6663	0.3214
2.7662+08	400.0000	442.6663	0.2471
3.0177+08	400.0000	442.6663	0.1727
3.2692+08	400.0000	442.6663	9.8306-02
3.5207+08	400.0000	442.6663	2.3926-02
3.6016+08	400.0000	442.6663	BUB>0.0
3.7721+08	400.0000	411.6920	0.0
4.0236+08	400.0000	364.0701	0.0
4.2751+08	400.0000	314.5800	0.0
4.5266+08	400.0000	263.6749	0.0
4.7780+08	400.0000	211.7582	0.0
5.0295+08	400.0000	159.2026	0.0
5.2810+08	400.0000	106.3625	0.0

HEATX HOT-TQCUR H-403   TQCURV INLET

  PRESSURE PROFILE: CONSTANT2
  PRESSURE DROP: 0.0   PSI
  PROPERTY OPTION SET: SRK   SOAVE-REDLICH-KWONG EQUATION OF STATE

DUTY BTU/HR	PRES PSIA	TEMP F	VFRAC
0.0	30.0878	1383.8782	1.0000
2.2058+07	30.0878	1348.8984	1.0000
2.5148+07	30.0878	1343.9881	1.0000
5.0295+07	30.0878	1303.9219	1.0000
7.5443+07	30.0878	1263.6733	1.0000
1.0059+08	30.0878	1223.2360	1.0000
1.2574+08	30.0878	1182.6036	1.0000
1.5089+08	30.0878	1141.7696	1.0000
1.7603+08	30.0878	1100.7272	1.0000
2.0118+08	30.0878	1059.4697	1.0000
2.2633+08	30.0878	1017.9905	1.0000
2.5148+08	30.0878	976.2830	1.0000
2.7662+08	30.0878	934.3407	1.0000
3.0177+08	30.0878	892.1573	1.0000
3.2692+08	30.0878	849.7271	1.0000
3.5207+08	30.0878	807.0445	1.0000
3.6016+08	30.0878	793.2600	1.0000
3.7721+08	30.0878	764.1048	1.0000
4.0236+08	30.0878	720.9040	1.0000
4.2751+08	30.0878	677.4392	1.0000
4.5266+08	30.0878	633.7086	1.0000
4.7780+08	30.0878	589.7118	1.0000
5.0295+08	30.0878	545.4501	1.0000
5.2810+08	30.0878	500.9266	1.0000

BLOCK: H-404   MODEL: HEATER

  INLET STREAM: S-421
  INLET HEAT STREAM: Q-203
  OUTLET STREAM: S-422
  PROPERTY OPTION SET: SRK   SOAVE-REDLICH-KWONG EQUATION OF STATE

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(LBMOL/HR)	74830.8	74830.8	0.00000

```
      MASS(LB/HR   )            0.209780E+07    0.209780E+07     0.00000
      ENTHALPY(BTU/HR  )       -0.128224E+10   -0.128224E+10     0.00000

                   ***  CO2 EQUIVALENT SUMMARY ***
   FEED STREAMS CO2E              333464.       LB/HR
   PRODUCT STREAMS CO2E           333464.       LB/HR
   NET STREAMS CO2E PRODUCTION    0.00000       LB/HR
   UTILITIES CO2E PRODUCTION      0.00000       LB/HR
   TOTAL CO2E PRODUCTION          0.00000       LB/HR

                       ***  INPUT DATA  ***
  TWO    PHASE  PQ  FLASH
  PRESSURE DROP                        PSI                        0.0
  DUTY FROM INLET HEAT STREAM(S)       BTU/HR           -3,320,720.
  MAXIMUM NO. ITERATIONS                                         30
  CONVERGENCE TOLERANCE                                           0.100000-05



                        ***  RESULTS  ***
  OUTLET TEMPERATURE    F                                    495.03
  OUTLET PRESSURE       PSIA                                 30.088
  OUTLET VAPOR FRACTION                                      1.0000



  V-L PHASE EQUILIBRIUM :

     COMP              F(I)           X(I)           Y(I)           K(I)
     BENZENE          0.10772E-03    0.39741E-08    0.10772E-03     114.29
     TOLUENE          0.14568E-05    0.35324E-11    0.14568E-05     144.82
     P-XYLENE         0.13034E-08    0.12090E-15    0.13034E-08     214.54
     M-XYLENE         0.11831E-08    0.15290E-15    0.11831E-08     203.17
     O-XYLENE         0.88305E-09    0.50252E-15    0.88305E-09     127.49
     WATER            0.10862         1.0000        0.10862         18.723
     METHANE          0.54477E-02    0.74559E-08    0.54477E-02     2961.9
     N2               0.73987        0.13453E-06    0.73987         7961.2
     H2               0.11735E-02    0.73035E-09    0.11735E-02     6241.1
     CO               0.69848E-04    0.13225E-10    0.69848E-04     7786.6
     CO2              0.51610E-01    0.38321E-05    0.51610E-01     1019.2
     NAPTH            0.76379E-08    0.22511E-12    0.76379E-08     15.088
     O2               0.93104E-01    0.28249E-06    0.93104E-01     3210.4

BLOCK:  H-405    MODEL: HEATER
------------------------------
  INLET STREAM:            S-422
  INLET HEAT STREAM:       Q-202
  OUTLET STREAM:           S-423
  PROPERTY OPTION SET:     SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

                   ***  MASS AND ENERGY BALANCE  ***
                                 IN              OUT         RELATIVE DIFF.
   TOTAL BALANCE
      MOLE(LBMOL/HR)             74830.8         74830.8         0.00000
      MASS(LB/HR   )            0.209780E+07    0.209780E+07     0.00000
      ENTHALPY(BTU/HR  )       -0.129344E+10   -0.129344E+10     0.00000
```

```
                  ***  CO2 EQUIVALENT SUMMARY ***
 FEED STREAMS CO2E             333464.      LB/HR
 PRODUCT STREAMS CO2E          333464.      LB/HR
 NET STREAMS CO2E PRODUCTION   0.00000      LB/HR
 UTILITIES CO2E PRODUCTION     0.00000      LB/HR
 TOTAL CO2E PRODUCTION         0.00000      LB/HR

                      ***  INPUT DATA  ***
TWO    PHASE  PQ  FLASH
PRESSURE DROP                       PSI                        0.0
DUTY FROM INLET HEAT STREAM(S)      BTU/HR                    -0.112080+08
MAXIMUM NO. ITERATIONS                                        30
CONVERGENCE TOLERANCE                                          0.100000-05



                       ***  RESULTS  ***
OUTLET TEMPERATURE    F                                    475.09
OUTLET PRESSURE       PSIA                                 30.088
OUTLET VAPOR FRACTION                                      1.0000



V-L PHASE EQUILIBRIUM :

   COMP              F(I)           X(I)           Y(I)           K(I)
   BENZENE          0.10772E-03    0.39741E-08    0.10772E-03     169.43
   TOLUENE          0.14568E-05    0.35324E-11    0.14568E-05     248.74
   P-XYLENE         0.13034E-08    0.12090E-15    0.13034E-08     438.13
   M-XYLENE         0.11831E-08    0.15290E-15    0.11831E-08     407.30
   O-XYLENE         0.88305E-09    0.50252E-15    0.88305E-09     241.91
   WATER            0.10862         1.0000        0.10862         15.837
   METHANE          0.54477E-02    0.74559E-08    0.54477E-02     4209.9
   N2               0.73987        0.13453E-06    0.73987         12022.
   H2               0.11735E-02    0.73035E-09    0.11735E-02     8688.1
   CO               0.69848E-04    0.13225E-10    0.69848E-04     11771.
   CO2              0.51610E-01    0.38321E-05    0.51610E-01     1290.0
   NAPTH            0.76379E-08    0.22511E-12    0.76379E-08     25.898
   O2               0.93104E-01    0.28249E-06    0.93104E-01     4361.2

BLOCK:  H-406    MODEL: HEATER
------------------------------
  INLET STREAM:           S-423
  INLET HEAT STREAM:      Q-201
  OUTLET STREAM:          S-424
  PROPERTY OPTION SET:    SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

                  ***  MASS AND ENERGY BALANCE  ***
                                 IN              OUT        RELATIVE DIFF.
 TOTAL BALANCE
    MOLE(LBMOL/HR)            74830.8         74830.8         0.00000
    MASS(LB/HR   )          0.209780E+07    0.209780E+07      0.00000
    ENTHALPY(BTU/HR  )     -0.134807E+10   -0.134807E+10      0.00000

                  ***  CO2 EQUIVALENT SUMMARY ***
 FEED STREAMS CO2E             333464.      LB/HR
 PRODUCT STREAMS CO2E          333464.      LB/HR
```

NET STREAMS CO2E PRODUCTION	0.00000	LB/HR
UTILITIES CO2E PRODUCTION	0.00000	LB/HR
TOTAL CO2E PRODUCTION	0.00000	LB/HR

*** INPUT DATA ***

TWO PHASE PQ FLASH		
PRESSURE DROP	PSI	0.0
DUTY FROM INLET HEAT STREAM(S)	BTU/HR	-0.546206+08
MAXIMUM NO. ITERATIONS		30
CONVERGENCE TOLERANCE		0.100000-05

*** RESULTS ***

OUTLET TEMPERATURE	F	377.20
OUTLET PRESSURE	PSIA	30.088
OUTLET VAPOR FRACTION		1.0000

V-L PHASE EQUILIBRIUM :

COMP	F(I)	X(I)	Y(I)	K(I)
BENZENE	0.10772E-03	0.39741E-08	0.10772E-03	560.53
TOLUENE	0.14568E-05	0.35324E-11	0.14568E-05	1415.2
P-XYLENE	0.13034E-08	0.12090E-15	0.13034E-08	4672.5
M-XYLENE	0.11831E-08	0.15290E-15	0.11831E-08	4082.3
O-XYLENE	0.88305E-09	0.50252E-15	0.88305E-09	1953.0
WATER	0.10862	1.0000	0.10862	5.9354
METHANE	0.54477E-02	0.74559E-08	0.54477E-02	13248.
N2	0.73987	0.13453E-06	0.73987	47658.
H2	0.11735E-02	0.73035E-09	0.11735E-02	26753.
CO	0.69848E-04	0.13225E-10	0.69848E-04	46673.
CO2	0.51610E-01	0.38321E-05	0.51610E-01	2393.2
NAPTH	0.76379E-08	0.22511E-12	0.76379E-08	140.65
O2	0.93104E-01	0.28249E-06	0.93104E-01	11514.

BLOCK: H-407 MODEL: HEATER

INLET STREAM:	S-419	
INLET HEAT STREAM:	Q-204	
OUTLET STREAM:	S-420	
PROPERTY OPTION SET:	SRK	SOAVE-REDLICH-KWONG EQUATION OF STATE

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(LBMOL/HR)	23000.0	23000.0	0.00000
MASS(LB/HR)	414351.	414351.	0.00000
ENTHALPY(BTU/HR)	-0.240752E+10	-0.240752E+10	-0.198061E-15

*** CO2 EQUIVALENT SUMMARY ***

FEED STREAMS CO2E	0.00000	LB/HR
PRODUCT STREAMS CO2E	0.00000	LB/HR
NET STREAMS CO2E PRODUCTION	0.00000	LB/HR
UTILITIES CO2E PRODUCTION	0.00000	LB/HR
TOTAL CO2E PRODUCTION	0.00000	LB/HR

```
                       ***  INPUT DATA  ***
TWO    PHASE  PQ  FLASH
PRESSURE DROP                        PSI                        7.00000
DUTY FROM INLET HEAT STREAM(S)       BTU/HR                -177,563.
MAXIMUM NO. ITERATIONS                                         30
CONVERGENCE TOLERANCE                                           0.100000-05



                        ***  RESULTS  ***
OUTLET TEMPERATURE    F                                    188.18
OUTLET PRESSURE       PSIA                                 8.0000
OUTLET VAPOR FRACTION                                      0.91541



V-L PHASE EQUILIBRIUM :

   COMP              F(I)           X(I)           Y(I)           K(I)
   WATER             1.0000         1.0000         1.0000         1.0000

BLOCK:  H-408    MODEL: HEATER
------------------------------
  INLET STREAM:           S-401
  OUTLET STREAM:          S-402
  OUTLET HEAT STREAM:     Q-104
  PROPERTY OPTION SET:    SRK      SOAVE-REDLICH-KWONG EQUATION OF STATE

                   ***  MASS AND ENERGY BALANCE  ***
                                IN              OUT        RELATIVE DIFF.
   TOTAL BALANCE
      MOLE(LBMOL/HR)          24636.5         24636.5         0.00000
      MASS(LB/HR   )          368978.         368978.         0.00000
      ENTHALPY(BTU/HR  )    -0.791512E+09   -0.791512E+09    0.150610E-15

                   ***  CO2 EQUIVALENT SUMMARY ***
   FEED STREAMS CO2E            0.774782E+07  LB/HR
   PRODUCT STREAMS CO2E         0.774782E+07  LB/HR
   NET STREAMS CO2E PRODUCTION   0.00000      LB/HR
   UTILITIES CO2E PRODUCTION     0.00000      LB/HR
   TOTAL CO2E PRODUCTION         0.00000      LB/HR

                       ***  INPUT DATA  ***
  TWO    PHASE  TP  FLASH
  SPECIFIED TEMPERATURE                F                        200.000
  PRESSURE DROP                        PSI                       15.0000
  MAXIMUM NO. ITERATIONS                                         30
  CONVERGENCE TOLERANCE                                           0.100000-05



                        ***  RESULTS  ***
  OUTLET TEMPERATURE    F                                    200.00
  OUTLET PRESSURE       PSIA                                 13.000
  HEAT DUTY             BTU/HR                              0.47831E+08
  OUTLET VAPOR FRACTION                                      1.0000
```

V-L PHASE EQUILIBRIUM :

COMP	F(I)	X(I)	Y(I)	K(I)
BENZENE	0.15425E-02	0.18481	0.15425E-02	1.9330
TOLUENE	0.20861E-04	0.59735E-02	0.20861E-04	0.80880
P-XYLENE	0.18664E-07	0.23410E-04	0.18664E-07	0.18465
M-XYLENE	0.16942E-07	0.20986E-04	0.16942E-07	0.18697
O-XYLENE	0.12645E-07	0.15885E-04	0.12645E-07	0.18435
METHANE	0.78006	0.69770	0.78006	258.93
N2	0.12389E-01	0.56340E-02	0.12389E-01	509.25
H2	0.16803	0.37362E-01	0.16803	1041.5
CO	0.10002E-02	0.48405E-03	0.10002E-02	478.52
CO2	0.36953E-01	0.67091E-01	0.36953E-01	127.56
NAPTH	0.10937E-06	0.88874E-03	0.10937E-06	0.28501E-01

```
BLOCK:  JACKET   MODEL: HEATER
------------------------------
  INLET STREAM:          S-214
  OUTLET STREAM:         S-215
  PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

                   ***  MASS AND ENERGY BALANCE  ***
                                 IN              OUT        RELATIVE DIFF.
   TOTAL BALANCE
      MOLE(LBMOL/HR)           48.6000         48.6000         0.00000
      MASS(LB/HR   )           5120.08         5120.08         0.00000
      ENTHALPY(BTU/HR  )      -405392.        -645751.        0.372216

                   ***  CO2 EQUIVALENT SUMMARY ***
   FEED STREAMS CO2E            0.00000      LB/HR
   PRODUCT STREAMS CO2E         0.00000      LB/HR
   NET STREAMS CO2E PRODUCTION  0.00000      LB/HR
   UTILITIES CO2E PRODUCTION    0.00000      LB/HR
   TOTAL CO2E PRODUCTION        0.00000      LB/HR

                       ***  INPUT DATA  ***
  TWO    PHASE  TP  FLASH
  SPECIFIED TEMPERATURE              F                        -13.0000
  PRESSURE DROP                      PSI                       16.0000
  MAXIMUM NO. ITERATIONS                                       30
  CONVERGENCE TOLERANCE                                         0.100000-05


                        ***  RESULTS  ***
  OUTLET TEMPERATURE    F                                  -13.000
  OUTLET PRESSURE       PSIA                                14.696
  HEAT DUTY             BTU/HR                           -0.24036E+06
  OUTLET VAPOR FRACTION                                     0.0000


  V-L PHASE EQUILIBRIUM :
```

```
     COMP              F(I)           X(I)           Y(I)           K(I)
     BENZENE          0.85964E-08    0.85964E-08    0.18022E-06    0.87435E-
02
     TOLUENE          0.58929E-01    0.58929E-01    0.23613        0.16712E-
02
     P-XYLENE         0.91718        0.91718        0.74787        0.34007E-
03
     M-XYLENE         0.11902E-01    0.11902E-01    0.90201E-02    0.31609E-
03
     O-XYLENE         0.11508E-01    0.11508E-01    0.69737E-02    0.25273E-
03
     NAPTH            0.48003E-03    0.48003E-03    0.63907E-05    0.55524E-
05

 BLOCK:  M-101    MODEL: MIXER
 -----------------------------
   INLET STREAMS:         S-101       S-126
   OUTLET STREAM:         S-102
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

                     ***  MASS AND ENERGY BALANCE  ***
                                  IN              OUT        RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(LBMOL/HR)           156450.         156450.         0.00000
       MASS(LB/HR   )          0.242839E+07    0.242839E+07     0.00000
       ENTHALPY(BTU/HR  )      -0.522351E+10   -0.522351E+10    0.182573E-15

                     ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E           0.517279E+08  LB/HR
    PRODUCT STREAMS CO2E        0.517279E+08  LB/HR
    NET STREAMS CO2E PRODUCTION   0.00000      LB/HR
    UTILITIES CO2E PRODUCTION     0.00000      LB/HR
    TOTAL CO2E PRODUCTION         0.00000      LB/HR

                         ***  INPUT DATA  ***
   TWO    PHASE      FLASH
   MAXIMUM NO. ITERATIONS                                  30
   CONVERGENCE TOLERANCE                                    0.100000-05
   OUTLET PRESSURE:  MINIMUM OF INLET STREAM PRESSURES

 BLOCK:  M-102    MODEL: MIXER
 -----------------------------
   INLET STREAMS:         S-104       S-106       S-108
   OUTLET STREAM:         S-109
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

                     ***  MASS AND ENERGY BALANCE  ***
                                  IN              OUT        RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(LBMOL/HR)           156450.         156450.         0.00000
       MASS(LB/HR   )          0.242839E+07    0.242839E+07   -0.191757E-15
       ENTHALPY(BTU/HR  )      -0.500110E+10   -0.500110E+10    0.00000

                     ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E           0.517279E+08  LB/HR
    PRODUCT STREAMS CO2E        0.517279E+08  LB/HR
```

```
   NET STREAMS CO2E PRODUCTION   0.00000      LB/HR
   UTILITIES CO2E PRODUCTION     0.00000      LB/HR
   TOTAL CO2E PRODUCTION         0.00000      LB/HR

                         ***  INPUT DATA  ***
  TWO    PHASE      FLASH
  MAXIMUM NO. ITERATIONS                                  30
  CONVERGENCE TOLERANCE                                    0.100000-05
  OUTLET PRESSURE:  MINIMUM OF INLET STREAM PRESSURES

BLOCK:  M-103    MODEL: MIXER
-----------------------------
  INLET STREAMS:         S-115       S-117       S-119
  OUTLET STREAM:         S-120
  PROPERTY OPTION SET:   SRK      SOAVE-REDLICH-KWONG EQUATION OF STATE

                     ***  MASS AND ENERGY BALANCE  ***
                                 IN              OUT        RELATIVE DIFF.
   TOTAL BALANCE
      MOLE(LBMOL/HR)           151521.         151521.         0.00000
      MASS(LB/HR   )          0.242839E+07    0.242839E+07   -0.191757E-15
      ENTHALPY(BTU/HR  )     -0.400074E+10   -0.400074E+10    0.119187E-15

                     ***  CO2 EQUIVALENT SUMMARY ***
   FEED STREAMS CO2E           0.469622E+08  LB/HR
   PRODUCT STREAMS CO2E        0.469622E+08  LB/HR
   NET STREAMS CO2E PRODUCTION   0.00000      LB/HR
   UTILITIES CO2E PRODUCTION     0.00000      LB/HR
   TOTAL CO2E PRODUCTION         0.00000      LB/HR

                         ***  INPUT DATA  ***
  TWO    PHASE      FLASH
  MAXIMUM NO. ITERATIONS                                  30
  CONVERGENCE TOLERANCE                                    0.100000-05
  OUTLET PRESSURE:  MINIMUM OF INLET STREAM PRESSURES

BLOCK:  M-201    MODEL: MIXER
-----------------------------
  INLET STREAMS:         S-309       S-201
  OUTLET STREAM:         S-202
  PROPERTY OPTION SET:   SRK      SOAVE-REDLICH-KWONG EQUATION OF STATE

                     ***  MASS AND ENERGY BALANCE  ***
                                 IN              OUT        RELATIVE DIFF.
   TOTAL BALANCE
      MOLE(LBMOL/HR)           2346.90         2346.90         0.00000
      MASS(LB/HR   )           204791.         204791.         0.00000
      ENTHALPY(BTU/HR  )      0.586457E+08    0.586457E+08    0.254088E-15

                     ***  CO2 EQUIVALENT SUMMARY ***
   FEED STREAMS CO2E             5695.48      LB/HR
   PRODUCT STREAMS CO2E          5695.48      LB/HR
   NET STREAMS CO2E PRODUCTION   0.00000      LB/HR
   UTILITIES CO2E PRODUCTION     0.00000      LB/HR
   TOTAL CO2E PRODUCTION         0.00000      LB/HR

                         ***  INPUT DATA  ***
```

```
  TWO    PHASE      FLASH
  MAXIMUM NO. ITERATIONS                                  30
  CONVERGENCE TOLERANCE                                    0.100000-05
  OUTLET PRESSURE:  MINIMUM OF INLET STREAM PRESSURES

BLOCK:  M-301    MODEL: MIXER
-----------------------------
  INLET STREAMS:         S-208       S-314
  OUTLET STREAM:         S-301
  PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

                     ***  MASS AND ENERGY BALANCE  ***
                                 IN              OUT        RELATIVE DIFF.
   TOTAL BALANCE
      MOLE(LBMOL/HR)           323.060         323.060       0.167161E-05
      MASS(LB/HR   )           16728.9         16728.9       0.963327E-06
      ENTHALPY(BTU/HR  )      -0.202718E+08   -0.202715E+08   -0.137728E-04

                     ***  CO2 EQUIVALENT SUMMARY ***
   FEED STREAMS CO2E            0.00000      LB/HR
   PRODUCT STREAMS CO2E         0.00000      LB/HR
   NET STREAMS CO2E PRODUCTION  0.00000      LB/HR
   UTILITIES CO2E PRODUCTION    0.00000      LB/HR
   TOTAL CO2E PRODUCTION        0.00000      LB/HR

                         ***  INPUT DATA  ***
  TWO    PHASE      FLASH
  MAXIMUM NO. ITERATIONS                                  30
  CONVERGENCE TOLERANCE                                    0.100000
  OUTLET PRESSURE:  MINIMUM OF INLET STREAM PRESSURES

BLOCK:  M-302    MODEL: MIXER
-----------------------------
  INLET STREAMS:         S-313       S-312
  OUTLET STREAM:         S-314
  PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

                     ***  MASS AND ENERGY BALANCE  ***
                                 IN              OUT        RELATIVE DIFF.
   TOTAL BALANCE
      MOLE(LBMOL/HR)           196.060         196.060         0.00000
      MASS(LB/HR   )           5027.15         5027.15         0.00000
      ENTHALPY(BTU/HR  )      -0.218276E+08   -0.218276E+08     0.00000

                     ***  CO2 EQUIVALENT SUMMARY ***
   FEED STREAMS CO2E            0.00000      LB/HR
   PRODUCT STREAMS CO2E         0.00000      LB/HR
   NET STREAMS CO2E PRODUCTION  0.00000      LB/HR
   UTILITIES CO2E PRODUCTION    0.00000      LB/HR
   TOTAL CO2E PRODUCTION        0.00000      LB/HR

                         ***  INPUT DATA  ***
  TWO    PHASE      FLASH
  MAXIMUM NO. ITERATIONS                                  30
  CONVERGENCE TOLERANCE                                    0.100000-05
  OUTLET PRESSURE:  MINIMUM OF INLET STREAM PRESSURES
```

```
BLOCK:  M-402    MODEL: MIXER
-----------------------------
  INLET STREAMS:         S-414       S-416       S-418
  OUTLET STREAM:         S-419
  PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

                     ***  MASS AND ENERGY BALANCE  ***
                                   IN               OUT        RELATIVE DIFF.
   TOTAL BALANCE
      MOLE(LBMOL/HR)           23000.0         23000.0         0.00000
      MASS(LB/HR   )           414351.         414351.         0.00000
      ENTHALPY(BTU/HR  )      -0.240735E+10   -0.240735E+10    0.198076E-15

                     ***  CO2 EQUIVALENT SUMMARY ***
   FEED STREAMS CO2E             0.00000      LB/HR
   PRODUCT STREAMS CO2E          0.00000      LB/HR
   NET STREAMS CO2E PRODUCTION   0.00000      LB/HR
   UTILITIES CO2E PRODUCTION     0.00000      LB/HR
   TOTAL CO2E PRODUCTION         0.00000      LB/HR

                         ***  INPUT DATA  ***
  TWO    PHASE      FLASH
  MAXIMUM NO. ITERATIONS                                    30
  CONVERGENCE TOLERANCE                                      0.100000-05
  OUTLET PRESSURE:  MINIMUM OF INLET STREAM PRESSURES

BLOCK:  P-201    MODEL: PUMP
----------------------------
  INLET STREAM:          S-204
  OUTLET STREAM:         S-205
  PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

                     ***  MASS AND ENERGY BALANCE  ***
                                   IN               OUT        RELATIVE DIFF.
   TOTAL BALANCE
      MOLE(LBMOL/HR)           2325.35         2325.35         0.00000
      MASS(LB/HR   )           204221.         204221.         0.00000
      ENTHALPY(BTU/HR  )       0.593101E+08    0.593469E+08   -0.620458E-03

                     ***  CO2 EQUIVALENT SUMMARY ***
   FEED STREAMS CO2E             0.00000      LB/HR
   PRODUCT STREAMS CO2E          0.00000      LB/HR
   NET STREAMS CO2E PRODUCTION   0.00000      LB/HR
   UTILITIES CO2E PRODUCTION     0.00000      LB/HR
   TOTAL CO2E PRODUCTION         0.00000      LB/HR

                         ***  INPUT DATA  ***
   OUTLET PRESSURE  PSIA                                   50.0000
   DRIVER EFFICIENCY                                        1.00000

   FLASH SPECIFICATIONS:
   LIQUID PHASE CALCULATION
   NO FLASH PERFORMED
   MAXIMUM NUMBER OF ITERATIONS                             30
   TOLERANCE                                                0.100000-05

                          ***  RESULTS  ***
```

```
   VOLUMETRIC FLOW RATE  CUFT/HR                          3,810.03
   PRESSURE CHANGE  PSI                                      37.0000
   NPSH AVAILABLE   FT-LBF/LB                                 6.66918
   FLUID POWER  HP                                           10.2525
   BRAKE POWER  HP                                           14.4717
   ELECTRICITY  KW                                           10.7915
   PUMP EFFICIENCY USED                                       0.70845
   NET WORK REQUIRED  HP                                     14.4717
   HEAD DEVELOPED FT-LBF/LB                                  99.4013

BLOCK:  P-202    MODEL: PUMP
----------------------------
  INLET STREAM:           S-209
  OUTLET STREAM:          S-210
  PROPERTY OPTION SET:    SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

                     ***  MASS AND ENERGY BALANCE  ***
                                  IN              OUT        RELATIVE DIFF.
   TOTAL BALANCE
      MOLE(LBMOL/HR)          438.059         438.059         0.00000
      MASS(LB/HR   )          55011.7         55011.7         0.00000
      ENTHALPY(BTU/HR  )     0.239069E+08    0.239124E+08   -0.229429E-03

                     ***  CO2 EQUIVALENT SUMMARY ***
   FEED STREAMS CO2E              0.00000      LB/HR
   PRODUCT STREAMS CO2E           0.00000      LB/HR
   NET STREAMS CO2E PRODUCTION    0.00000      LB/HR
   UTILITIES CO2E PRODUCTION      0.00000      LB/HR
   TOTAL CO2E PRODUCTION          0.00000      LB/HR

                         ***  INPUT DATA  ***
   PRESSURE CHANGE  PSI                                      16.0000
   DRIVER EFFICIENCY                                          1.00000

   FLASH SPECIFICATIONS:
   LIQUID PHASE CALCULATION
   NO FLASH PERFORMED
   MAXIMUM NUMBER OF ITERATIONS                               30
   TOLERANCE                                                  0.100000-05

                          ***  RESULTS  ***
   VOLUMETRIC FLOW RATE  CUFT/HR                          1,056.76
   PRESSURE CHANGE  PSI                                      16.0000
   NPSH AVAILABLE   FT-LBF/LB                                 0.0
   FLUID POWER  HP                                            1.22968
   BRAKE POWER  HP                                            2.15616
   ELECTRICITY  KW                                            1.60785
   PUMP EFFICIENCY USED                                       0.57031
   NET WORK REQUIRED  HP                                      2.15616
   HEAD DEVELOPED FT-LBF/LB                                  44.2592

BLOCK:  P-203    MODEL: PUMP
----------------------------
  INLET STREAM:           S-211
  OUTLET STREAM:          S-213
  PROPERTY OPTION SET:    SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE
```

```
                    ***  MASS AND ENERGY BALANCE  ***
                                  IN                OUT        RELATIVE DIFF.
   TOTAL BALANCE
      MOLE(LBMOL/HR)           48.6000          48.6000          0.00000
      MASS(LB/HR   )           5120.08          5120.08          0.00000
      ENTHALPY(BTU/HR  )      -9671.08         -7488.18        -0.225714

                    ***  CO2 EQUIVALENT SUMMARY ***
   FEED STREAMS CO2E            0.00000      LB/HR
   PRODUCT STREAMS CO2E         0.00000      LB/HR
   NET STREAMS CO2E PRODUCTION  0.00000      LB/HR
   UTILITIES CO2E PRODUCTION    0.00000      LB/HR
   TOTAL CO2E PRODUCTION        0.00000      LB/HR

                        ***  INPUT DATA  ***
   PRESSURE CHANGE  PSI                                      32.0000
   DRIVER EFFICIENCY                                          1.00000

   FLASH SPECIFICATIONS:
   LIQUID PHASE CALCULATION
   NO FLASH PERFORMED
   MAXIMUM NUMBER OF ITERATIONS                               30
   TOLERANCE                                                  0.100000-05

                         ***  RESULTS  ***
   VOLUMETRIC FLOW RATE  CUFT/HR                            108.989
   PRESSURE CHANGE  PSI                                      32.0000
   NPSH AVAILABLE   FT-LBF/LB                                 0.0
   FLUID POWER  HP                                            0.25365
   BRAKE POWER  HP                                            0.85791
   ELECTRICITY  KW                                            0.63974
   PUMP EFFICIENCY USED                                       0.29566
   NET WORK REQUIRED  HP                                      0.85791
   HEAD DEVELOPED FT-LBF/LB                                  98.0888

BLOCK:  P-204    MODEL: PUMP
----------------------------
  INLET STREAM:          S-212
  OUTLET STREAM:         S-218
  PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

                    ***  MASS AND ENERGY BALANCE  ***
                                  IN                OUT        RELATIVE DIFF.
   TOTAL BALANCE
      MOLE(LBMOL/HR)           389.459          389.459          0.00000
      MASS(LB/HR   )           49891.6          49891.6          0.00000
      ENTHALPY(BTU/HR  )      0.236025E+08    0.236131E+08   -0.449762E-03

                    ***  CO2 EQUIVALENT SUMMARY ***
   FEED STREAMS CO2E            0.00000      LB/HR
   PRODUCT STREAMS CO2E         0.00000      LB/HR
   NET STREAMS CO2E PRODUCTION  0.00000      LB/HR
   UTILITIES CO2E PRODUCTION    0.00000      LB/HR
   TOTAL CO2E PRODUCTION        0.00000      LB/HR

                        ***  INPUT DATA  ***
   PRESSURE CHANGE  PSI                                      34.0000
```

```
   DRIVER EFFICIENCY                                       1.00000

   FLASH SPECIFICATIONS:
   LIQUID PHASE CALCULATION
   NO FLASH PERFORMED
   MAXIMUM NUMBER OF ITERATIONS                            30
   TOLERANCE                                               0.100000-05

                       ***  RESULTS  ***
   VOLUMETRIC FLOW RATE  CUFT/HR                         937.510
   PRESSURE CHANGE  PSI                                   34.0000
   NPSH AVAILABLE   FT-LBF/LB                              0.0
   FLUID POWER  HP                                         2.31821
   BRAKE POWER  HP                                         4.17392
   ELECTRICITY  KW                                         3.11249
   PUMP EFFICIENCY USED                                    0.55540
   NET WORK REQUIRED  HP                                   4.17392
   HEAD DEVELOPED FT-LBF/LB                               92.0004

BLOCK:  P-301    MODEL: PUMP
----------------------------
  INLET STREAM:           S-301
  OUTLET STREAM:          S-302
  PROPERTY OPTION SET:    SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

                  ***  MASS AND ENERGY BALANCE  ***
                                 IN              OUT        RELATIVE DIFF.
   TOTAL BALANCE
      MOLE(LBMOL/HR)          323.060         323.060         0.00000
      MASS(LB/HR   )          16728.9         16728.9       -0.434933E-15
      ENTHALPY(BTU/HR  )    -0.202715E+08   -0.202687E+08   -0.139239E-03

                  ***  CO2 EQUIVALENT SUMMARY ***
   FEED STREAMS CO2E            0.00000      LB/HR
   PRODUCT STREAMS CO2E         0.00000      LB/HR
   NET STREAMS CO2E PRODUCTION  0.00000      LB/HR
   UTILITIES CO2E PRODUCTION    0.00000      LB/HR
   TOTAL CO2E PRODUCTION        0.00000      LB/HR

                      ***  INPUT DATA  ***
   OUTLET PRESSURE  PSIA                                  52.0000
   PUMP EFFICIENCY                                         0.70000
   DRIVER EFFICIENCY                                       1.00000

   FLASH SPECIFICATIONS:
   LIQUID PHASE CALCULATION
   NO FLASH PERFORMED
   MAXIMUM NUMBER OF ITERATIONS                            30
   TOLERANCE                                               0.100000-05

                       ***  RESULTS  ***
   VOLUMETRIC FLOW RATE  CUFT/HR                         333.663
   PRESSURE CHANGE  PSI                                   32.0000
   NPSH AVAILABLE   FT-LBF/LB                             27.0312
   FLUID POWER  HP                                         0.77653
   BRAKE POWER  HP                                         1.10932
   ELECTRICITY  KW                                         0.82722
```

```
  PUMP EFFICIENCY USED                                   0.70000
  NET WORK REQUIRED  HP                                  1.10932
  HEAD DEVELOPED FT-LBF/LB                              91.9079

BLOCK:  P-302    MODEL: PUMP
----------------------------
 INLET STREAM:          S-306
 OUTLET STREAM:         S-307
 PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

                    ***  MASS AND ENERGY BALANCE  ***
                                  IN              OUT        RELATIVE DIFF.
  TOTAL BALANCE
     MOLE(LBMOL/HR)            323.060         323.060         0.00000
     MASS(LB/HR   )            16728.9         16728.9         0.00000
     ENTHALPY(BTU/HR  )      -0.219039E+08   -0.219006E+08   -0.149044E-03

                    ***  CO2 EQUIVALENT SUMMARY ***
  FEED STREAMS CO2E             0.00000      LB/HR
  PRODUCT STREAMS CO2E          0.00000      LB/HR
  NET STREAMS CO2E PRODUCTION   0.00000      LB/HR
  UTILITIES CO2E PRODUCTION     0.00000      LB/HR
  TOTAL CO2E PRODUCTION         0.00000      LB/HR

                        ***  INPUT DATA  ***
  OUTLET PRESSURE  PSIA                                 44.0000
  PUMP EFFICIENCY                                        0.70000
  DRIVER EFFICIENCY                                      1.00000

  FLASH SPECIFICATIONS:
  2 PHASE FLASH
  MAXIMUM NUMBER OF ITERATIONS                           30
  TOLERANCE                                              0.100000-05

                         ***  RESULTS  ***
  VOLUMETRIC FLOW RATE  CUFT/HR                        324.985
  PRESSURE CHANGE  PSI                                  38.0000
  NPSH AVAILABLE   FT-LBF/LB                             0.0
  FLUID POWER  HP                                        0.89814
  BRAKE POWER  HP                                        1.28306
  ELECTRICITY  KW                                        0.95678
  PUMP EFFICIENCY USED                                   0.70000
  NET WORK REQUIRED  HP                                  1.28306
  HEAD DEVELOPED FT-LBF/LB                             106.302

BLOCK:  P-401    MODEL: PUMP
----------------------------
 INLET STREAM:          S-410
 OUTLET STREAM:         S-411
 PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

                    ***  MASS AND ENERGY BALANCE  ***
                                  IN              OUT        RELATIVE DIFF.
  TOTAL BALANCE
     MOLE(LBMOL/HR)            23000.0         23000.0         0.00000
     MASS(LB/HR   )            414351.         414351.         0.00000
     ENTHALPY(BTU/HR  )      -0.284251E+10   -0.284185E+10   -0.231247E-03
```

```
                   ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E              0.00000      LB/HR
    PRODUCT STREAMS CO2E           0.00000      LB/HR
    NET STREAMS CO2E PRODUCTION    0.00000      LB/HR
    UTILITIES CO2E PRODUCTION      0.00000      LB/HR
    TOTAL CO2E PRODUCTION          0.00000      LB/HR

                       ***  INPUT DATA  ***
    OUTLET PRESSURE  PSIA                                      400.000
    DRIVER EFFICIENCY                                            1.00000

    FLASH SPECIFICATIONS:
    LIQUID PHASE CALCULATION
    NO FLASH PERFORMED
    MAXIMUM NUMBER OF ITERATIONS                                 30
    TOLERANCE                                                    0.100000-05

                        ***  RESULTS  ***
    VOLUMETRIC FLOW RATE  CUFT/HR                            7,009.06
    PRESSURE CHANGE  PSI                                       385.304
    NPSH AVAILABLE   FT-LBF/LB                                  33.6194
    FLUID POWER  HP                                            196.409
    BRAKE POWER  HP                                            258.337
    ELECTRICITY  KW                                            192.642
    PUMP EFFICIENCY USED                                         0.76028
    NET WORK REQUIRED  HP                                      258.337
    HEAD DEVELOPED FT-LBF/LB                                   938.549

 BLOCK:  R-101    MODEL: RYIELD
 ------------------------------
   INLET STREAM:          S-111
   OUTLET STREAM:         S-112
   PROPERTY OPTION SET:   SRK      SOAVE-REDLICH-KWONG EQUATION OF STATE


     ***********************************************************************
     *                                                                     *
     *     SPECIFIED YIELDS HAVE BEEN NORMALIZED TO MAINTAIN MASS BALANCE  *
     *                                                                     *
     ***********************************************************************


                   ***  MASS AND ENERGY BALANCE  ***
                             IN             OUT        GENERATION    RELATIVE
DIFF.
   TOTAL BALANCE
   MOLE(LBMOL/HR)         156450.       151521.      -4928.35     -0.575104E-
08
   MASS(LB/HR   )        0.242839E+07  0.242839E+07                -0.588337E-
08
   ENTHALPY(BTU/HR  )   -0.244457E+10 -0.244457E+10                 0.186721E-
06

                   ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E            0.517279E+08  LB/HR
    PRODUCT STREAMS CO2E         0.469622E+08  LB/HR
```

```
 NET STREAMS CO2E PRODUCTION -0.476572E+07  LB/HR
 UTILITIES CO2E PRODUCTION     0.00000      LB/HR
 TOTAL CO2E PRODUCTION       -0.476572E+07  LB/HR

                      ***  INPUT DATA  ***
TWO    PHASE  PQ  FLASH
PRESSURE DROP          PSI                              16.0000
SPECIFIED HEAT DUTY    BTU/HR                            0.0
MAXIMUM NO. ITERATIONS                                  30
CONVERGENCE TOLERANCE                                    0.100000-05

 MOLE-YIELD
  SUBSTREAM MIXED   :
  BENZENE   0.130E-01    TOLUENE   0.600E-03    P-XYLENE  0.400E-05
  M-XYLENE  0.400E-05    O-XYLENE  0.400E-05    METHANE   0.780
  H2        0.168        CO        0.100E-02    CO2       0.370E-01
  NAPTH     0.260E-02

INERTS:        N2

                       ***  RESULTS  ***
OUTLET TEMPERATURE    F                                  1238.5
OUTLET PRESSURE       PSIA                               43.000
HEAT DUTY             BTU/HR                             0.0000
VAPOR FRACTION                                           1.0000



V-L PHASE EQUILIBRIUM :

   COMP             F(I)          X(I)          Y(I)          K(I)
   BENZENE         0.12813E-01   0.12813E-01   0.12813E-01    MISSING
   TOLUENE         0.59137E-03   0.59137E-03   0.59137E-03    MISSING
   P-XYLENE        0.39424E-05   0.39424E-05   0.39424E-05    MISSING
   M-XYLENE        0.39424E-05   0.39424E-05   0.39424E-05    MISSING
   O-XYLENE        0.39424E-05   0.39424E-05   0.39424E-05    MISSING
   METHANE         0.76878       0.76878       0.76878        MISSING
   N2              0.12208E-01   0.12208E-01   0.12208E-01    MISSING
   H2              0.16558       0.16558       0.16558        MISSING
   CO              0.98561E-03   0.98561E-03   0.98561E-03    MISSING
   CO2             0.36468E-01   0.36468E-01   0.36468E-01    MISSING
   NAPTH           0.25626E-02   0.25626E-02   0.25626E-02    MISSING

BLOCK:  R-301    MODEL: RSTOIC
------------------------------
 INLET STREAM:           S-303
 OUTLET STREAM:          S-304
 PROPERTY OPTION SET:    SRK      SOAVE-REDLICH-KWONG EQUATION OF STATE

                    ***  MASS AND ENERGY BALANCE  ***
                             IN            OUT         GENERATION    RELATIVE
DIFF.
 TOTAL BALANCE
 MOLE(LBMOL/HR)         323.060       323.060       0.00000       0.00000
 MASS(LB/HR   )          16728.9       16728.9                    0.217466E-
15
```

```
   ENTHALPY(BTU/HR  )    -0.745864E+07 -0.745864E+07               -0.249730E-
15

                    ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E             0.00000      LB/HR
    PRODUCT STREAMS CO2E          0.00000      LB/HR
    NET STREAMS CO2E PRODUCTION   0.00000      LB/HR
    UTILITIES CO2E PRODUCTION     0.00000      LB/HR
    TOTAL CO2E PRODUCTION         0.00000      LB/HR

                        ***  INPUT DATA  ***
   STOICHIOMETRY MATRIX:

    REACTION #   1:
     SUBSTREAM MIXED   :
     TOLUENE   -1.00    P-XYLENE   1.00    METHANOL  -1.00    WATER      1.00


   REACTION CONVERSION SPECS: NUMBER=    1
     REACTION #   1:
     SUBSTREAM:MIXED    KEY COMP:TOLUENE  CONV FRAC: 0.3540



   TWO    PHASE  PQ  FLASH
   PRESSURE DROP         PSI                                17.0000
   SPECIFIED HEAT DUTY   BTU/HR                              0.0
   MAXIMUM NO. ITERATIONS                                   30
   CONVERGENCE TOLERANCE                                     0.100000-05
   SIMULTANEOUS REACTIONS
   GENERATE COMBUSTION REACTIONS FOR FEED SPECIES          NO

                         ***  RESULTS  ***
   OUTLET TEMPERATURE    F                                    1231.4
   OUTLET PRESSURE       PSIA                                 28.000
   VAPOR FRACTION                                             1.0000



   REACTION EXTENTS:

      REACTION          REACTION
      NUMBER            EXTENT
                        LBMOL/HR
      1                  45.174

   V-L PHASE EQUILIBRIUM :

      COMP              F(I)           X(I)           Y(I)           K(I)
      BENZENE          0.10527E-04    0.10527E-04    0.10527E-04     MISSING
      TOLUENE          0.25517        0.25517        0.25517         MISSING
      P-XYLENE         0.14009        0.14009        0.14009         MISSING
      M-XYLENE         0.25907E-08    0.25907E-08    0.25907E-08     MISSING
      O-XYLENE         0.42460E-10    0.42460E-10    0.42460E-10     MISSING
      METHANOL         0.17845        0.17845        0.17845         MISSING
      WATER            0.42628        0.42628        0.42628         MISSING
```

```
BLOCK:  SEP-201  MODEL: SEP
---------------------------
  INLET STREAM:           S-202
  OUTLET STREAMS:         S-204       S-203
  PROPERTY OPTION SET:    SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

                     ***  MASS AND ENERGY BALANCE  ***
                                IN              OUT        RELATIVE DIFF.
   TOTAL BALANCE
      MOLE(LBMOL/HR)            2346.90         2346.90         0.00000
      MASS(LB/HR   )            204791.         204791.       -0.142115E-15
      ENTHALPY(BTU/HR  )       0.586457E+08    0.575398E+08    0.188570E-01

                     ***  CO2 EQUIVALENT SUMMARY ***
   FEED STREAMS CO2E             5695.48      LB/HR
   PRODUCT STREAMS CO2E          5695.48      LB/HR
   NET STREAMS CO2E PRODUCTION   0.00000      LB/HR
   UTILITIES CO2E PRODUCTION     0.00000      LB/HR
   TOTAL CO2E PRODUCTION         0.00000      LB/HR


                         ***  INPUT DATA  ***

  FLASH SPECS FOR STREAM S-204
  TWO    PHASE  TP  FLASH
  PRESSURE DROP         PSI                                   0.0
  MAXIMUM NO. ITERATIONS                                    30
  CONVERGENCE TOLERANCE                                       0.100000-05

  FLASH SPECS FOR STREAM S-203
  TWO    PHASE  TP  FLASH
  PRESSURE DROP         PSI                                   0.0
  MAXIMUM NO. ITERATIONS                                    30
  CONVERGENCE TOLERANCE                                       0.100000-05

  FRACTION OF FEED
    SUBSTREAM= MIXED
      STREAM= S-203     CPT= BENZENE   FRACTION=          0.0
                             TOLUENE                      0.0
                             P-XYLENE                     0.0
                             M-XYLENE                     0.0
                             O-XYLENE                     0.0
                             METHANOL                     0.0
                             WATER                        0.0
                             METHANE                      1.00000
                             N2                           1.00000
                             H2                           1.00000
                             CO                           1.00000
                             CO2                          1.00000
                             NAPTH                        0.0


                          ***  RESULTS  ***

  HEAT DUTY             BTU/HR                              -0.11059E+07
```

```
 COMPONENT = BENZENE
   STREAM     SUBSTREAM    SPLIT FRACTION
   S-204      MIXED                 1.00000

 COMPONENT = TOLUENE
   STREAM     SUBSTREAM    SPLIT FRACTION
   S-204      MIXED                 1.00000

 COMPONENT = P-XYLENE
   STREAM     SUBSTREAM    SPLIT FRACTION
   S-204      MIXED                 1.00000

 COMPONENT = M-XYLENE
   STREAM     SUBSTREAM    SPLIT FRACTION
   S-204      MIXED                 1.00000

 COMPONENT = O-XYLENE
   STREAM     SUBSTREAM    SPLIT FRACTION
   S-204      MIXED                 1.00000

 COMPONENT = METHANOL
   STREAM     SUBSTREAM    SPLIT FRACTION
   S-204      MIXED                 1.00000

 COMPONENT = WATER
   STREAM     SUBSTREAM    SPLIT FRACTION
   S-204      MIXED                 1.00000

 COMPONENT = METHANE
   STREAM     SUBSTREAM    SPLIT FRACTION
   S-203      MIXED                 1.00000

 COMPONENT = N2
   STREAM     SUBSTREAM    SPLIT FRACTION
   S-203      MIXED                 1.00000

 COMPONENT = H2
   STREAM     SUBSTREAM    SPLIT FRACTION
   S-203      MIXED                 1.00000

 COMPONENT = CO
   STREAM     SUBSTREAM    SPLIT FRACTION
   S-203      MIXED                 1.00000

 COMPONENT = CO2
   STREAM     SUBSTREAM    SPLIT FRACTION
   S-203      MIXED                 1.00000

 COMPONENT = NAPTH
   STREAM     SUBSTREAM    SPLIT FRACTION
   S-204      MIXED                 1.00000

BLOCK:  SPL-101  MODEL: FSPLIT
------------------------------
  INLET STREAM:          S-102
  OUTLET STREAMS:        S-103       S-105       S-107
  PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE
```

```
                    ***  MASS AND ENERGY BALANCE  ***
                                  IN              OUT        RELATIVE DIFF.
   TOTAL BALANCE
      MOLE(LBMOL/HR)           156450.         156450.         0.00000
      MASS(LB/HR   )          0.242839E+07    0.242839E+07     0.00000
      ENTHALPY(BTU/HR  )     -0.522351E+10   -0.522351E+10   -0.182573E-15

                    ***  CO2 EQUIVALENT SUMMARY ***
   FEED STREAMS CO2E            0.517279E+08  LB/HR
   PRODUCT STREAMS CO2E         0.517279E+08  LB/HR
   NET STREAMS CO2E PRODUCTION   0.00000      LB/HR
   UTILITIES CO2E PRODUCTION     0.00000      LB/HR
   TOTAL CO2E PRODUCTION         0.00000      LB/HR

                        ***  INPUT DATA  ***

 FRACTION OF FLOW                STRM=S-103    FRAC=         0.33333
                                 STRM=S-105    FRAC=         0.33333

                         ***  RESULTS  ***

 STREAM= S-103          SPLIT=          0.33333     KEY=  0    STREAM-ORDER=
1
        S-105                                      0.33333                0
2
        S-107                                      0.33333                0
3

BLOCK:  SPL-102  MODEL: FSPLIT
------------------------------
  INLET STREAM:          S-113
  OUTLET STREAMS:        S-114       S-116       S-118
  PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

                    ***  MASS AND ENERGY BALANCE  ***
                                  IN              OUT        RELATIVE DIFF.
   TOTAL BALANCE
      MOLE(LBMOL/HR)           151521.         151521.         0.00000
      MASS(LB/HR   )          0.242839E+07    0.242839E+07     0.00000
      ENTHALPY(BTU/HR  )     -0.434419E+10   -0.434419E+10     0.00000

                    ***  CO2 EQUIVALENT SUMMARY ***
   FEED STREAMS CO2E            0.469622E+08  LB/HR
   PRODUCT STREAMS CO2E         0.469622E+08  LB/HR
   NET STREAMS CO2E PRODUCTION   0.00000      LB/HR
   UTILITIES CO2E PRODUCTION     0.00000      LB/HR
   TOTAL CO2E PRODUCTION         0.00000      LB/HR

                        ***  INPUT DATA  ***

 FRACTION OF FLOW                STRM=S-114    FRAC=         0.33333
                                 STRM=S-116    FRAC=         0.33333

                         ***  RESULTS  ***
```

```
  STREAM= S-114          SPLIT=          0.33333     KEY=  0    STREAM-ORDER=
1
        S-116                            0.33333                 0
2
        S-118                            0.33334                 0
3

 BLOCK:  SPL-103  MODEL: FSPLIT
 ------------------------------
   INLET STREAM:          S-125
   OUTLET STREAMS:        S-127       S-126
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

                     ***  MASS AND ENERGY BALANCE  ***
                                 IN              OUT        RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(LBMOL/HR)            149312.        149312.         0.00000
       MASS(LB/HR   )           0.223623E+07    0.223623E+07     0.00000
       ENTHALPY(BTU/HR  )      -0.479704E+10   -0.479704E+10    0.198805E-15

                     ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E            0.469565E+08  LB/HR
    PRODUCT STREAMS CO2E         0.469565E+08  LB/HR
    NET STREAMS CO2E PRODUCTION   0.00000      LB/HR
    UTILITIES CO2E PRODUCTION     0.00000      LB/HR
    TOTAL CO2E PRODUCTION         0.00000      LB/HR

                         ***  INPUT DATA  ***

  FRACTION OF FLOW                STRM=S-127    FRAC=         0.20000

                          ***  RESULTS  ***

  STREAM= S-127          SPLIT=          0.20000     KEY=  0    STREAM-ORDER=
1
        S-126                            0.80000                 0
2

 BLOCK:  SPL-301  MODEL: FSPLIT
 ------------------------------
   INLET STREAM:          S-310
   OUTLET STREAMS:        S-311       S-312
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

                     ***  MASS AND ENERGY BALANCE  ***
                                 IN              OUT        RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(LBMOL/HR)            185.383        185.383         0.00000
       MASS(LB/HR   )            4094.41        4094.41         0.00000
       ENTHALPY(BTU/HR  )      -0.213095E+08   -0.213095E+08    0.349637E-15

                     ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E             0.00000      LB/HR
    PRODUCT STREAMS CO2E          0.00000      LB/HR
    NET STREAMS CO2E PRODUCTION   0.00000      LB/HR
    UTILITIES CO2E PRODUCTION     0.00000      LB/HR
    TOTAL CO2E PRODUCTION         0.00000      LB/HR
```

```
                        ***  INPUT DATA  ***

 FRACTION OF FLOW                STRM=S-311    FRAC=         0.32000

                         ***  RESULTS  ***

 STREAM= S-311          SPLIT=          0.32000     KEY=  0    STREAM-ORDER=
1
        S-312                                   0.68000                 0
2

BLOCK:  SPL-401  MODEL: FSPLIT
------------------------------
  INLET STREAM:          S-127
  OUTLET STREAMS:        S-403      S-401
  PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

                    ***  MASS AND ENERGY BALANCE  ***
                                 IN              OUT        RELATIVE DIFF.
   TOTAL BALANCE
      MOLE(LBMOL/HR)            29862.4         29862.4         0.00000
      MASS(LB/HR   )            447246.         447246.         0.00000
      ENTHALPY(BTU/HR  )      -0.959408E+09   -0.959408E+09    0.124253E-15

                    ***  CO2 EQUIVALENT SUMMARY ***
   FEED STREAMS CO2E           0.939129E+07  LB/HR
   PRODUCT STREAMS CO2E        0.939129E+07  LB/HR
   NET STREAMS CO2E PRODUCTION   0.00000      LB/HR
   UTILITIES CO2E PRODUCTION     0.00000      LB/HR
   TOTAL CO2E PRODUCTION         0.00000      LB/HR

                        ***  INPUT DATA  ***

 FRACTION OF FLOW                STRM=S-403    FRAC=         0.17500

 STREAM CALCULATION ORDER:
       STREAM        ORDER
         S-403         1

                         ***  RESULTS  ***

 STREAM= S-403          SPLIT=          0.17500     KEY=  0    STREAM-ORDER=
1
        S-401                                   0.82500                 0
2

BLOCK:  SPL-403  MODEL: FSPLIT
------------------------------
  INLET STREAM:          S-412
  OUTLET STREAMS:        S-413      S-415      S-417
  PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

                    ***  MASS AND ENERGY BALANCE  ***
                                 IN              OUT        RELATIVE DIFF.
   TOTAL BALANCE
      MOLE(LBMOL/HR)            23000.0         23000.0         0.00000
```

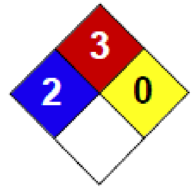
```
      MASS(LB/HR   )            414351.        414351.        0.00000
      ENTHALPY(BTU/HR  )      -0.231376E+10  -0.231376E+10     0.00000

                  ***  CO2 EQUIVALENT SUMMARY ***
   FEED STREAMS CO2E            0.00000      LB/HR
   PRODUCT STREAMS CO2E         0.00000      LB/HR
   NET STREAMS CO2E PRODUCTION  0.00000      LB/HR
   UTILITIES CO2E PRODUCTION    0.00000      LB/HR
   TOTAL CO2E PRODUCTION        0.00000      LB/HR

                      ***  INPUT DATA  ***

 FRACTION OF FLOW               STRM=S-413    FRAC=         0.33333
                                STRM=S-415    FRAC=         0.33333

                       ***  RESULTS  ***

 STREAM= S-413          SPLIT=         0.33333     KEY=  0    STREAM-ORDER=
1
        S-415                                     0.33333                 0
2
        S-417                                     0.33333                 0
3

BLOCK:  T-401    MODEL: COMPR
-----------------------------
  INLET STREAM:          S-413
  OUTLET STREAM:         S-414
  PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

                  ***  MASS AND ENERGY BALANCE  ***
                                IN              OUT        RELATIVE DIFF.
   TOTAL BALANCE
      MOLE(LBMOL/HR)            7666.67        7666.67        0.00000
      MASS(LB/HR   )            138117.        138117.        0.00000
      ENTHALPY(BTU/HR  )      -0.771252E+09  -0.802449E+09    0.388773E-01

                  ***  CO2 EQUIVALENT SUMMARY ***
   FEED STREAMS CO2E            0.00000      LB/HR
   PRODUCT STREAMS CO2E         0.00000      LB/HR
   NET STREAMS CO2E PRODUCTION  0.00000      LB/HR
   UTILITIES CO2E PRODUCTION    0.00000      LB/HR
   TOTAL CO2E PRODUCTION        0.00000      LB/HR

                       ***  INPUT DATA  ***

  ISENTROPIC TURBINE
   OUTLET PRESSURE  PSIA                                   15.0000
   ISENTROPIC EFFICIENCY                                    0.85000
   MECHANICAL EFFICIENCY                                    1.00000

                       ***  RESULTS  ***

   INDICATED  HORSEPOWER REQUIREMENT  HP             -12,260.9
   BRAKE      HORSEPOWER REQUIREMENT  HP             -12,260.9
   NET WORK REQUIRED                  HP             -12,260.9
   POWER LOSSES                       HP                   0.0
```

```
   ISENTROPIC HORSEPOWER REQUIREMENT  HP              -14,424.6
   CALCULATED OUTLET TEMP  F                              217.393
   ISENTROPIC TEMPERATURE  F                              217.393
   EFFICIENCY (POLYTR/ISENTR) USED                          0.85000
   OUTLET VAPOR FRACTION                                    0.90191
   HEAD DEVELOPED,       FT-LBF/LB                 -206,786.
   MECHANICAL EFFICIENCY USED                               1.00000
   INLET HEAT CAPACITY RATIO                                1.41305
   INLET VOLUMETRIC FLOW RATE , CUFT/HR              190,765.
   OUTLET VOLUMETRIC FLOW RATE, CUFT/HR            3,321,290.
   INLET  COMPRESSIBILITY FACTOR                            0.92530
   OUTLET COMPRESSIBILITY FACTOR                            0.89435
   AV. ISENT. VOL. EXPONENT                                 1.16727
   AV. ISENT. TEMP EXPONENT                                 1.13570
   AV. ACTUAL VOL. EXPONENT                                 1.14923
   AV. ACTUAL TEMP EXPONENT                                 1.13570

BLOCK:  T-402    MODEL: COMPR
-----------------------------
  INLET STREAM:          S-415
  OUTLET STREAM:         S-416
  PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

                    ***  MASS AND ENERGY BALANCE  ***
                                  IN              OUT        RELATIVE DIFF.
   TOTAL BALANCE
      MOLE(LBMOL/HR)          7666.67         7666.67         0.00000
      MASS(LB/HR   )          138117.         138117.         0.00000
      ENTHALPY(BTU/HR  )    -0.771252E+09   -0.802449E+09    0.388773E-01

                    ***  CO2 EQUIVALENT SUMMARY ***
   FEED STREAMS CO2E            0.00000      LB/HR
   PRODUCT STREAMS CO2E         0.00000      LB/HR
   NET STREAMS CO2E PRODUCTION   0.00000      LB/HR
   UTILITIES CO2E PRODUCTION     0.00000      LB/HR
   TOTAL CO2E PRODUCTION        0.00000      LB/HR

                         ***  INPUT DATA  ***

  ISENTROPIC TURBINE
   OUTLET PRESSURE  PSIA                                  15.0000
   ISENTROPIC EFFICIENCY                                    0.85000
   MECHANICAL EFFICIENCY                                    1.00000

                         ***  RESULTS  ***

   INDICATED  HORSEPOWER REQUIREMENT  HP              -12,260.9
   BRAKE      HORSEPOWER REQUIREMENT  HP              -12,260.9
   NET WORK REQUIRED                  HP              -12,260.9
   POWER LOSSES                       HP                    0.0
   ISENTROPIC HORSEPOWER REQUIREMENT  HP              -14,424.6
   CALCULATED OUTLET TEMP  F                              217.393
   ISENTROPIC TEMPERATURE  F                              217.393
   EFFICIENCY (POLYTR/ISENTR) USED                          0.85000
   OUTLET VAPOR FRACTION                                    0.90191
   HEAD DEVELOPED,       FT-LBF/LB                 -206,786.
   MECHANICAL EFFICIENCY USED                               1.00000
```

```
  INLET HEAT CAPACITY RATIO                                  1.41305
  INLET VOLUMETRIC FLOW RATE , CUFT/HR                190,765.
  OUTLET VOLUMETRIC FLOW RATE, CUFT/HR              3,321,290.
  INLET  COMPRESSIBILITY FACTOR                              0.92530
  OUTLET COMPRESSIBILITY FACTOR                              0.89435
  AV. ISENT. VOL. EXPONENT                                   1.16727
  AV. ISENT. TEMP EXPONENT                                   1.13570
  AV. ACTUAL VOL. EXPONENT                                   1.14923
  AV. ACTUAL TEMP EXPONENT                                   1.13570

BLOCK:  T-403    MODEL: COMPR
-----------------------------
 INLET STREAM:          S-417
 OUTLET STREAM:         S-418
 PROPERTY OPTION SET:   SRK      SOAVE-REDLICH-KWONG EQUATION OF STATE

                   ***  MASS AND ENERGY BALANCE  ***
                                 IN              OUT        RELATIVE DIFF.
  TOTAL BALANCE
     MOLE(LBMOL/HR)            7666.67        7666.67         0.00000
     MASS(LB/HR   )            138117.        138117.         0.00000
     ENTHALPY(BTU/HR  )      -0.771252E+09   -0.802449E+09    0.388773E-01

                   ***  CO2 EQUIVALENT SUMMARY ***
  FEED STREAMS CO2E             0.00000      LB/HR
  PRODUCT STREAMS CO2E          0.00000      LB/HR
  NET STREAMS CO2E PRODUCTION   0.00000      LB/HR
  UTILITIES CO2E PRODUCTION     0.00000      LB/HR
  TOTAL CO2E PRODUCTION         0.00000      LB/HR

                        ***  INPUT DATA  ***

 ISENTROPIC TURBINE
  OUTLET PRESSURE  PSIA                                     15.0000
  ISENTROPIC EFFICIENCY                                      0.85000
  MECHANICAL EFFICIENCY                                      1.00000

                        ***  RESULTS  ***

  INDICATED  HORSEPOWER REQUIREMENT  HP               -12,260.9
  BRAKE      HORSEPOWER REQUIREMENT  HP               -12,260.9
  NET WORK REQUIRED                  HP               -12,260.9
  POWER LOSSES                       HP                     0.0
  ISENTROPIC HORSEPOWER REQUIREMENT  HP               -14,424.6
  CALCULATED OUTLET TEMP  F                               217.393
  ISENTROPIC TEMPERATURE  F                               217.393
  EFFICIENCY (POLYTR/ISENTR) USED                            0.85000
  OUTLET VAPOR FRACTION                                      0.90191
  HEAD DEVELOPED,       FT-LBF/LB                    -206,786.
  MECHANICAL EFFICIENCY USED                                 1.00000
  INLET HEAT CAPACITY RATIO                                  1.41305
  INLET VOLUMETRIC FLOW RATE , CUFT/HR                190,765.
  OUTLET VOLUMETRIC FLOW RATE, CUFT/HR              3,321,290.
  INLET  COMPRESSIBILITY FACTOR                              0.92530
  OUTLET COMPRESSIBILITY FACTOR                              0.89435
  AV. ISENT. VOL. EXPONENT                                   1.16727
  AV. ISENT. TEMP EXPONENT                                   1.13570
```

AV. ACTUAL VOL. EXPONENT	1.14923
AV. ACTUAL TEMP EXPONENT	1.13570

Appendix C: Thermophysical Data & Material Safety Data Sheets



Health	2
Fire	3
Reactivity	0
Personal Protection	H

Material Safety Data Sheet
Benzene MSDS

Section 1: Chemical Product and Company Identification

Product Name: Benzene

Catalog Codes: SLB1564, SLB3055, SLB2881

CAS#: 71-43-2

RTECS: CY1400000

TSCA: TSCA 8(b) inventory: Benzene

CI#: Not available.

Synonym: Benzol; Benzine

Chemical Name: Benzene

Chemical Formula: C6-H6

Contact Information:

Sciencelab.com, Inc.
14025 Smith Rd.
Houston, Texas 77396

US Sales: **1-800-901-7247**
International Sales: **1-281-441-4400**

Order Online: ScienceLab.com

CHEMTREC (24HR Emergency Telephone), call:
1-800-424-9300

International CHEMTREC, call: 1-703-527-3887

For non-emergency assistance, call: 1-281-441-4400

Section 2: Composition and Information on Ingredients

Composition:

Name	CAS #	% by Weight
Benzene	71-43-2	100

Toxicological Data on Ingredients: Benzene: ORAL (LD50): Acute: 930 mg/kg [Rat]. 4700 mg/kg [Mouse]. DERMAL (LD50): Acute: >9400 mg/kg [Rabbit]. VAPOR (LC50): Acute: 10000 ppm 7 hours [Rat].

Section 3: Hazards Identification

Potential Acute Health Effects:
Very hazardous in case of eye contact (irritant), of inhalation. Hazardous in case of skin contact (irritant, permeator), of ingestion. Inflammation of the eye is characterized by redness, watering, and itching.

Potential Chronic Health Effects:
CARCINOGENIC EFFECTS: Classified A1 (Confirmed for human.) by ACGIH, 1 (Proven for human.) by IARC. MUTAGENIC EFFECTS: Classified POSSIBLE for human. Mutagenic for mammalian somatic cells. Mutagenic for bacteria and/or yeast. TERATOGENIC EFFECTS: Not available. DEVELOPMENTAL TOXICITY: Classified Reproductive system/toxin/female [POSSIBLE]. The substance is toxic to blood, bone marrow, central nervous system (CNS). The substance may be toxic to liver, Urinary System. Repeated or prolonged exposure to the substance can produce target organs damage.

Section 4: First Aid Measures

Eye Contact:
Check for and remove any contact lenses. In case of contact, immediately flush eyes with plenty of water for at least 15 minutes. Cold water may be used. WARM water MUST be used. Get medical attention immediately.

Skin Contact:
In case of contact, immediately flush skin with plenty of water. Cover the irritated skin with an emollient. Remove contaminated clothing and shoes. Wash clothing before reuse. Thoroughly clean shoes before reuse. Get medical attention.

Serious Skin Contact:
Wash with a disinfectant soap and cover the contaminated skin with an anti-bacterial cream. Seek immediate medical attention.

Inhalation:
If inhaled, remove to fresh air. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. Get medical attention if symptoms appear.

Serious Inhalation:
Evacuate the victim to a safe area as soon as possible. Loosen tight clothing such as a collar, tie, belt or waistband. If breathing is difficult, administer oxygen. If the victim is not breathing, perform mouth-to-mouth resuscitation. Seek medical attention.

Ingestion:
Do NOT induce vomiting unless directed to do so by medical personnel. Never give anything by mouth to an unconscious person. If large quantities of this material are swallowed, call a physician immediately. Loosen tight clothing such as a collar, tie, belt or waistband.

Serious Ingestion: Not available.

Section 5: Fire and Explosion Data

Flammability of the Product: Flammable.

Auto-Ignition Temperature: 497.78°C (928°F)

Flash Points: CLOSED CUP: -11.1°C (12°F). (Setaflash)

Flammable Limits: LOWER: 1.2% UPPER: 7.8%

Products of Combustion: These products are carbon oxides (CO, CO2).

Fire Hazards in Presence of Various Substances:
Highly flammable in presence of open flames and sparks, of heat. Slightly flammable to flammable in presence of oxidizing materials. Non-flammable in presence of shocks.

Explosion Hazards in Presence of Various Substances:
Risks of explosion of the product in presence of mechanical impact: Not available. Risks of explosion of the product in presence of static discharge: Not available. Explosive in presence of oxidizing materials, of acids.

Fire Fighting Media and Instructions:
Flammable liquid, soluble or dispersed in water. SMALL FIRE: Use DRY chemical powder. LARGE FIRE: Use alcohol foam, water spray or fog.

Special Remarks on Fire Hazards:
Extremely flammable liquid and vapor. Vapor may cause flash fire. Reacts on contact with iodine heptafluoride gas. Dioxygenyl tetrafluoroborate is as very powferful oxidant. The addition of a small particle to small samples of benzene, at ambient temperature, causes ignition. Contact with sodium peroxide with benzene causes ignition. Benzene ignites in contact with powdered chromic anhydride. Virgorous or incandescent reaction with hydrogen + Raney nickel (above 210 C) and bromine trifluoride.

Special Remarks on Explosion Hazards:
Benzene vapors + chlorine and light causes explosion. Reacts explosively with bromine pentafluoride, chlorine, chlorine trifluoride, diborane, nitric acid, nitryl perchlorate, liquid oxygen, ozone, silver perchlorate. Benzene + pentafluoride and methoxide (from arsenic pentafluoride and potassium methoxide) in trichlorotrifluoroethane causes explosion. Interaction

of nitryl perchlorate with benzene gave a slight explosion and flash. The solution of permanganic acid (or its explosive anhydride, dimaganese heptoxide) produced by interaction of permanganates and sulfuric acid will explode on contact with benzene. Peroxodisulfuric acid is a very powferful oxidant. Uncontrolled contact with benzene may cause explosion. Mixtures of peroxomonsulfuric acid with benzene explodes.

Section 6: Accidental Release Measures

Small Spill: Absorb with an inert material and put the spilled material in an appropriate waste disposal.

Large Spill:
Flammable liquid. Keep away from heat. Keep away from sources of ignition. Stop leak if without risk. Absorb with DRY earth, sand or other non-combustible material. Do not touch spilled material. Prevent entry into sewers, basements or confined areas; dike if needed. Be careful that the product is not present at a concentration level above TLV. Check TLV on the MSDS and with local authorities.

Section 7: Handling and Storage

Precautions:
Keep locked up.. Keep away from heat. Keep away from sources of ignition. Ground all equipment containing material. Do not ingest. Do not breathe gas/fumes/ vapor/spray. In case of insufficient ventilation, wear suitable respiratory equipment. If ingested, seek medical advice immediately and show the container or the label. Avoid contact with skin and eyes. Keep away from incompatibles such as oxidizing agents, acids.

Storage:
Store in a segregated and approved area. Keep container in a cool, well-ventilated area. Keep container tightly closed and sealed until ready for use. Avoid all possible sources of ignition (spark or flame).

Section 8: Exposure Controls/Personal Protection

Engineering Controls:
Provide exhaust ventilation or other engineering controls to keep the airborne concentrations of vapors below their respective threshold limit value. Ensure that eyewash stations and safety showers are proximal to the work-station location.

Personal Protection:
Splash goggles. Lab coat. Vapor respirator. Be sure to use an approved/certified respirator or equivalent. Gloves.

Personal Protection in Case of a Large Spill:
Splash goggles. Full suit. Vapor respirator. Boots. Gloves. A self contained breathing apparatus should be used to avoid inhalation of the product. Suggested protective clothing might not be sufficient; consult a specialist BEFORE handling this product.

Exposure Limits:
TWA: 0.5 STEL: 2.5 (ppm) from ACGIH (TLV) [United States] TWA: 1.6 STEL: 8 (mg/m3) from ACGIH (TLV) [United States] TWA: 0.1 STEL: 1 from NIOSH TWA: 1 STEL: 5 (ppm) from OSHA (PEL) [United States] TWA: 10 (ppm) from OSHA (PEL) [United States] TWA: 3 (ppm) [United Kingdom (UK)] TWA: 1.6 (mg/m3) [United Kingdom (UK)] TWA: 1 (ppm) [Canada] TWA: 3.2 (mg/m3) [Canada] TWA: 0.5 (ppm) [Canada]Consult local authorities for acceptable exposure limits.

Section 9: Physical and Chemical Properties

Physical state and appearance: Liquid.

Odor:
Aromatic. Gasoline-like, rather pleasant. (Strong.)

Taste: Not available.

Molecular Weight: 78.11 g/mole

Color: Clear Colorless. Colorless to light yellow.

pH (1% soln/water): Not available.

Boiling Point: 80.1 (176.2°F)

Melting Point: 5.5°C (41.9°F)

Critical Temperature: 288.9°C (552°F)

Specific Gravity: 0.8787 @ 15 C (Water = 1)

Vapor Pressure: 10 kPa (@ 20°C)

Vapor Density: 2.8 (Air = 1)

Volatility: Not available.

Odor Threshold: 4.68 ppm

Water/Oil Dist. Coeff.: The product is more soluble in oil; log(oil/water) = 2.1

Ionicity (in Water): Not available.

Dispersion Properties: See solubility in water, diethyl ether, acetone.

Solubility:
Miscible in alcohol, chloroform, carbon disulfide oils, carbon tetrachloride, glacial acetic acid, diethyl ether, acetone. Very slightly soluble in cold water.

Section 10: Stability and Reactivity Data

Stability: The product is stable.

Instability Temperature: Not available.

Conditions of Instability: Heat, ignition sources, incompatibles.

Incompatibility with various substances: Highly reactive with oxidizing agents, acids.

Corrosivity: Non-corrosive in presence of glass.

Special Remarks on Reactivity:
Benzene vapors + chlorine and light causes explosion. Reacts explosively with bromine pentafluoride, chlorine, chlorine trifluoride, diborane, nitric acid, nitryl perchlorate, liquid oxygen, ozone, silver perchlorate. Benzene + pentafluoride and methoxide (from arsenic pentafluoride and potassium methoxide) in trichlorotrifluoroethane causes explosion. Interaction of nitryl perchlorate with benzene gave a slight explosion and flash. The solution of permanganic acid (or its explosive anhydride, dimaganese heptoxide) produced by interaction of permanganates and sulfuric acid will explode on contact with benzene. Peroxodisulfuric acid is a very powferful oxidant. Uncontrolled contact with benzene may cause explosion. Mixtures of peroxomonsulfuric acid with benzene explodes.

Special Remarks on Corrosivity: Not available.

Polymerization: Will not occur.

Section 11: Toxicological Information

Routes of Entry: Absorbed through skin. Dermal contact. Eye contact. Inhalation.

Toxicity to Animals:
WARNING: THE LC50 VALUES HEREUNDER ARE ESTIMATED ON THE BASIS OF A 4-HOUR EXPOSURE. Acute oral toxicity (LD50): 930 mg/kg [Rat]. Acute dermal toxicity (LD50): >9400 mg/kg [Rabbit]. Acute toxicity of the vapor (LC50): 10000 7 hours [Rat].

Chronic Effects on Humans:

CARCINOGENIC EFFECTS: Classified A1 (Confirmed for human.) by ACGIH, 1 (Proven for human.) by IARC. MUTAGENIC EFFECTS: Classified POSSIBLE for human. Mutagenic for mammalian somatic cells. Mutagenic for bacteria and/or yeast. DEVELOPMENTAL TOXICITY: Classified Reproductive system/toxin/female [POSSIBLE]. Causes damage to the following organs: blood, bone marrow, central nervous system (CNS). May cause damage to the following organs: liver, Urinary System.

Other Toxic Effects on Humans:
Very hazardous in case of inhalation. Hazardous in case of skin contact (irritant, permeator), of ingestion.

Special Remarks on Toxicity to Animals: Not available.

Special Remarks on Chronic Effects on Humans:
May cause adverse reproductive effects (female fertility, Embryotoxic and/or foetotoxic in animal) and birth defects. May affect genetic material (mutagenic). May cause cancer (tumorigenic, leukemia)) Human: passes the placental barrier, detected in maternal milk.

Special Remarks on other Toxic Effects on Humans:
Acute Potential Health Effects: Skin: Causes skin irritation. It can be absorbed through intact skin and affect the liver, blood, metabolism,and urinary system. Eyes: Causes eye irritation. Inhalation: Causes respiratory tract and mucous membrane irritation. Can be absorbed through the lungs. May affect behavior/Central and Peripheral nervous systems (somnolence, muscle weakness, general anesthetic, and other symptoms similar to ingestion), gastrointestinal tract (nausea), blood metabolism, urinary system. Ingestion: May be harmful if swallowed. May cause gastrointestinal tract irritation including vomiting. May affect behavior/Central and Peripheral nervous systems (convulsions, seizures, tremor, irritability, initial CNS stimulation followed by depression, loss of coordination, dizziness, headache, weakness, pallor, flushing), respiration (breathlessness and chest constriction), cardiovascular system, (shallow/rapid pulse), and blood.

Section 12: Ecological Information

Ecotoxicity: Not available.

BOD5 and COD: Not available.

Products of Biodegradation:
Possibly hazardous short term degradation products are not likely. However, long term degradation products may arise.

Toxicity of the Products of Biodegradation: The products of degradation are less toxic than the product itself.

Special Remarks on the Products of Biodegradation: Not available.

Section 13: Disposal Considerations

Waste Disposal:
Waste must be disposed of in accordance with federal, state and local environmental control regulations.

Section 14: Transport Information

DOT Classification: CLASS 3: Flammable liquid.

Identification: : Benzene UNNA: 1114 PG: II

Special Provisions for Transport: Not available.

Section 15: Other Regulatory Information

Federal and State Regulations:
California prop. 65: This product contains the following ingredients for which the State of California has found to cause cancer, birth defects or other reproductive harm, which would require a warning under the statute: Benzene California prop. 65 (no significant risk level): Benzene: 0.007 mg/day (value) California prop. 65: This product contains the following ingredients

for which the State of California has found to cause cancer which would require a warning under the statute: Benzene Connecticut carcinogen reporting list.: Benzene Connecticut hazardous material survey.: Benzene Illinois toxic substances disclosure to employee act: Benzene Illinois chemical safety act: Benzene New York release reporting list: Benzene Rhode Island RTK hazardous substances: Benzene Pennsylvania RTK: Benzene Minnesota: Benzene Michigan critical material: Benzene Massachusetts RTK: Benzene Massachusetts spill list: Benzene New Jersey: Benzene New Jersey spill list: Benzene Louisiana spill reporting: Benzene California Director's list of Hazardous Substances: Benzene TSCA 8(b) inventory: Benzene SARA 313 toxic chemical notification and release reporting: Benzene CERCLA: Hazardous substances.: Benzene: 10 lbs. (4.536 kg)

Other Regulations:
OSHA: Hazardous by definition of Hazard Communication Standard (29 CFR 1910.1200). EINECS: This product is on the European Inventory of Existing Commercial Chemical Substances.

Other Classifications:

WHMIS (Canada):
CLASS B-2: Flammable liquid with a flash point lower than 37.8°C (100°F). CLASS D-2A: Material causing other toxic effects (VERY TOXIC).

DSCL (EEC):
R11- Highly flammable. R22- Harmful if swallowed. R38- Irritating to skin. R41- Risk of serious damage to eyes. R45- May cause cancer. R62- Possible risk of impaired fertility. S2- Keep out of the reach of children. S26- In case of contact with eyes, rinse immediately with plenty of water and seek medical advice. S39- Wear eye/face protection. S46- If swallowed, seek medical advice immediately and show this container or label. S53- Avoid exposure - obtain special instructions before use.

HMIS (U.S.A.):

Health Hazard: 2

Fire Hazard: 3

Reactivity: 0

Personal Protection: h

National Fire Protection Association (U.S.A.):

Health: 2

Flammability: 3

Reactivity: 0

Specific hazard:

Protective Equipment:
Gloves. Lab coat. Vapor respirator. Be sure to use an approved/certified respirator or equivalent. Wear appropriate respirator when ventilation is inadequate. Splash goggles.

Section 16: Other Information

References: Not available.

Other Special Considerations: Not available.

Created: 10/10/2005 08:35 PM

Last Updated: 05/21/2013 12:00 PM

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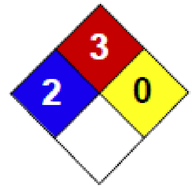

Health	2
Fire	3
Reactivity	0
Personal Protection	H

Material Safety Data Sheet
Toluene MSDS

Section 1: Chemical Product and Company Identification

Product Name: Toluene

Catalog Codes: SLT2857, SLT3277

CAS#: 108-88-3

RTECS: XS5250000

TSCA: TSCA 8(b) inventory: Toluene

CI#: Not available.

Synonym: Toluol, Tolu-Sol; Methylbenzene; Methacide; Phenylmethane; Methylbenzol

Chemical Name: Toluene

Chemical Formula: C6-H5-CH3 or C7-H8

Contact Information:

Sciencelab.com, Inc.
14025 Smith Rd.
Houston, Texas 77396

US Sales: **1-800-901-7247**
International Sales: **1-281-441-4400**

Order Online: ScienceLab.com

CHEMTREC (24HR Emergency Telephone), call:
1-800-424-9300

International CHEMTREC, call: 1-703-527-3887

For non-emergency assistance, call: 1-281-441-4400

Section 2: Composition and Information on Ingredients

Composition:

Name	CAS #	% by Weight
Toluene	108-88-3	100

Toxicological Data on Ingredients: Toluene: ORAL (LD50): Acute: 636 mg/kg [Rat]. DERMAL (LD50): Acute: 14100 mg/kg [Rabbit]. VAPOR (LC50): Acute: 49000 mg/m 4 hours [Rat]. 440 ppm 24 hours [Mouse].

Section 3: Hazards Identification

Potential Acute Health Effects:
Hazardous in case of skin contact (irritant), of eye contact (irritant), of ingestion, of inhalation. Slightly hazardous in case of skin contact (permeator).

Potential Chronic Health Effects:
CARCINOGENIC EFFECTS: A4 (Not classifiable for human or animal.) by ACGIH, 3 (Not classifiable for human.) by IARC. MUTAGENIC EFFECTS: Not available. TERATOGENIC EFFECTS: Not available. DEVELOPMENTAL TOXICITY: Not available. The substance may be toxic to blood, kidneys, the nervous system, liver, brain, central nervous system (CNS). Repeated or prolonged exposure to the substance can produce target organs damage.

Section 4: First Aid Measures

Eye Contact:
Check for and remove any contact lenses. In case of contact, immediately flush eyes with plenty of water for at least 15 minutes. Get medical attention.

Skin Contact:
In case of contact, immediately flush skin with plenty of water. Cover the irritated skin with an emollient. Remove contaminated clothing and shoes. Wash clothing before reuse. Thoroughly clean shoes before reuse. Get medical attention.

Serious Skin Contact:
Wash with a disinfectant soap and cover the contaminated skin with an anti-bacterial cream. Seek immediate medical attention.

Inhalation:
If inhaled, remove to fresh air. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. Get medical attention.

Serious Inhalation:
Evacuate the victim to a safe area as soon as possible. Loosen tight clothing such as a collar, tie, belt or waistband. If breathing is difficult, administer oxygen. If the victim is not breathing, perform mouth-to-mouth resuscitation. WARNING: It may be hazardous to the person providing aid to give mouth-to-mouth resuscitation when the inhaled material is toxic, infectious or corrosive. Seek medical attention.

Ingestion:
Do NOT induce vomiting unless directed to do so by medical personnel. Never give anything by mouth to an unconscious person. If large quantities of this material are swallowed, call a physician immediately. Loosen tight clothing such as a collar, tie, belt or waistband.

Serious Ingestion: Not available.

Section 5: Fire and Explosion Data

Flammability of the Product: Flammable.

Auto-Ignition Temperature: 480°C (896°F)

Flash Points: CLOSED CUP: 4.4444°C (40°F). (Setaflash) OPEN CUP: 16°C (60.8°F).

Flammable Limits: LOWER: 1.1% UPPER: 7.1%

Products of Combustion: These products are carbon oxides (CO, CO_2).

Fire Hazards in Presence of Various Substances:
Flammable in presence of open flames and sparks, of heat. Non-flammable in presence of shocks.

Explosion Hazards in Presence of Various Substances:
Risks of explosion of the product in presence of mechanical impact: Not available. Risks of explosion of the product in presence of static discharge: Not available.

Fire Fighting Media and Instructions:
Flammable liquid, insoluble in water. SMALL FIRE: Use DRY chemical powder. LARGE FIRE: Use water spray or fog.

Special Remarks on Fire Hazards: Not available.

Special Remarks on Explosion Hazards:
Toluene forms explosive reaction with 1,3-dichloro-5,5-dimethyl-2,4-imidazolididione; dinitrogen tetraoxide; concentrated nitric acid, sulfuric acid + nitric acid; N_2O_4; $AgClO_4$; BrF_3; Uranium hexafluoride; sulfur dichloride. Also forms an explosive mixture with tetranitromethane.

Section 6: Accidental Release Measures

Small Spill: Absorb with an inert material and put the spilled material in an appropriate waste disposal.

Large Spill:
Toxic flammable liquid, insoluble or very slightly soluble in water. Keep away from heat. Keep away from sources of ignition. Stop leak if without risk. Absorb with DRY earth, sand or other non-combustible material. Do not get water inside container. Do not touch spilled material. Prevent entry into sewers, basements or confined areas; dike if needed. Call for assistance on disposal. Be careful that the product is not present at a concentration level above TLV. Check TLV on the MSDS and with local authorities.

Section 7: Handling and Storage

Precautions:
Keep away from heat. Keep away from sources of ignition. Ground all equipment containing material. Do not ingest. Do not breathe gas/fumes/ vapor/spray. Wear suitable protective clothing. In case of insufficient ventilation, wear suitable respiratory equipment. If ingested, seek medical advice immediately and show the container or the label. Avoid contact with skin and eyes. Keep away from incompatibles such as oxidizing agents.

Storage:
Store in a segregated and approved area. Keep container in a cool, well-ventilated area. Keep container tightly closed and sealed until ready for use. Avoid all possible sources of ignition (spark or flame).

Section 8: Exposure Controls/Personal Protection

Engineering Controls:
Provide exhaust ventilation or other engineering controls to keep the airborne concentrations of vapors below their respective threshold limit value. Ensure that eyewash stations and safety showers are proximal to the work-station location.

Personal Protection:
Splash goggles. Lab coat. Vapor respirator. Be sure to use an approved/certified respirator or equivalent. Gloves.

Personal Protection in Case of a Large Spill:
Splash goggles. Full suit. Vapor respirator. Boots. Gloves. A self contained breathing apparatus should be used to avoid inhalation of the product. Suggested protective clothing might not be sufficient; consult a specialist BEFORE handling this product.

Exposure Limits:
TWA: 200 STEL: 500 CEIL: 300 (ppm) from OSHA (PEL) [United States] TWA: 50 (ppm) from ACGIH (TLV) [United States] SKIN TWA: 100 STEL: 150 from NIOSH [United States] TWA: 375 STEL: 560 (mg/m3) from NIOSH [United States] Consult local authorities for acceptable exposure limits.

Section 9: Physical and Chemical Properties

Physical state and appearance: Liquid.

Odor: Sweet, pungent, Benzene-like.

Taste: Not available.

Molecular Weight: 92.14 g/mole

Color: Colorless.

pH (1% soln/water): Not applicable.

Boiling Point: 110.6°C (231.1°F)

Melting Point: -95°C (-139°F)

Critical Temperature: 318.6°C (605.5°F)

Specific Gravity: 0.8636 (Water = 1)

Vapor Pressure: 3.8 kPa (@ 25°C)

Vapor Density: 3.1 (Air = 1)

Volatility: Not available.

Odor Threshold: 1.6 ppm

Water/Oil Dist. Coeff.: The product is more soluble in oil; log(oil/water) = 2.7

Ionicity (in Water): Not available.

Dispersion Properties: See solubility in water, diethyl ether, acetone.

Solubility:
Soluble in diethyl ether, acetone. Practically insoluble in cold water. Soluble in ethanol, benzene, chloroform, glacial acetic acid, carbon disulfide. Solubility in water: 0.561 g/l @ 25 deg. C.

Section 10: Stability and Reactivity Data

Stability: The product is stable.

Instability Temperature: Not available.

Conditions of Instability: Heat, ignition sources (flames, sparks, static), incompatible materials

Incompatibility with various substances: Reactive with oxidizing agents.

Corrosivity: Non-corrosive in presence of glass.

Special Remarks on Reactivity:
Incompatible with strong oxidizers, silver perchlorate, sodium difluoride, Tetranitromethane, Uranium Hexafluoride. Frozen Bromine Trifluoride reacts violently with Toluene at -80 deg. C. Reacts chemically with nitrogen oxides, or halogens to form nitrotoluene, nitrobenzene, and nitrophenol and halogenated products, respectively.

Special Remarks on Corrosivity: Not available.

Polymerization: Will not occur.

Section 11: Toxicological Information

Routes of Entry: Absorbed through skin. Dermal contact. Eye contact. Inhalation. Ingestion.

Toxicity to Animals:
WARNING: THE LC50 VALUES HEREUNDER ARE ESTIMATED ON THE BASIS OF A 4-HOUR EXPOSURE. Acute oral toxicity (LD50): 636 mg/kg [Rat]. Acute dermal toxicity (LD50): 14100 mg/kg [Rabbit]. Acute toxicity of the vapor (LC50): 440 24 hours [Mouse].

Chronic Effects on Humans:
CARCINOGENIC EFFECTS: A4 (Not classifiable for human or animal.) by ACGIH, 3 (Not classifiable for human.) by IARC. May cause damage to the following organs: blood, kidneys, the nervous system, liver, brain, central nervous system (CNS).

Other Toxic Effects on Humans:
Hazardous in case of skin contact (irritant), of ingestion, of inhalation. Slightly hazardous in case of skin contact (permeator).

Special Remarks on Toxicity to Animals:
Lowest Published Lethal Dose: LDL [Human] - Route: Oral; Dose: 50 mg/kg LCL [Rabbit] - Route: Inhalation; Dose: 55000 ppm/40min

Special Remarks on Chronic Effects on Humans:
Detected in maternal milk in human. Passes through the placental barrier in human. Embryotoxic and/or foetotoxic in animal. May cause adverse reproductive effects and birth defects (teratogenic). May affect genetic material (mutagenic)

Special Remarks on other Toxic Effects on Humans:

Acute Potential Health Effects: Skin: Causes mild to moderate skin irritation. It can be absorbed to some extent through the skin. Eyes: Cauess mild to moderate eye irritation with a burning sensation. Splash contact with eyes also causes conjunctivitis, blepharospasm, corneal edema, corneal abraisons. This usually resolves in 2 days. Inhalation: Inhalation of vapor may cause respiratory tract irritation causing coughing and wheezing, and nasal discharge. Inhalation of high concentrations may affect behavior and cause central nervous system effects characterized by nausea, headache, dizziness, tremors, restlessness, lightheadedness, exhilaration, memory loss, insomnia, impaired reaction time, drowsiness, ataxia, hallucinations, somnolence, muscle contraction or spasticity, unconsciousness and coma. Inhalation of high concentration of vapor may also affect the cardiovascular system (rapid heart beat, heart palpitations, increased or decreased blood pressure, dysrhythmia,), respiration (acute pulmonary edema, respiratory depression, apnea, asphyxia), cause vision disturbances and dilated pupils, and cause loss of appetite. Ingestion: Aspiration hazard. Aspiration of Toluene into the lungs may cause chemical pneumonitis. May cause irritation of the digestive tract with nausea, vomiting, pain. May have effects similar to that of acute inhalation. Chronic Potential Health Effects: Inhalation and Ingestion: Prolonged or repeated exposure via inhalation may cause central nervous system and cardiovascular symptoms similar to that of acute inhalation and ingestion as well liver damage/failure, kidney damage/failure (with hematuria, proteinuria, oliguria, renal tubular acidosis), brain damage, weight loss, blood (pigmented or nucleated red blood cells, changes in white blood cell count), bone marrow changes, electrolyte imbalances (Hypokalemia, Hypophostatemia), severe, muscle weakness and Rhabdomyolysis. Skin: Repeated or prolonged skin contact may cause defatting dermatitis.

Section 12: Ecological Information

Ecotoxicity:
Ecotoxicity in water (LC50): 313 mg/l 48 hours [Daphnia (daphnia)]. 17 mg/l 24 hours [Fish (Blue Gill)]. 13 mg/l 96 hours [Fish (Blue Gill)]. 56 mg/l 24 hours [Fish (Fathead minnow)]. 34 mg/l 96 hours [Fish (Fathead minnow)]. 56.8 ppm any hours [Fish (Goldfish)].

BOD5 and COD: Not available.

Products of Biodegradation:
Possibly hazardous short term degradation products are not likely. However, long term degradation products may arise.

Toxicity of the Products of Biodegradation: The products of degradation are less toxic than the product itself.

Special Remarks on the Products of Biodegradation: Not available.

Section 13: Disposal Considerations

Waste Disposal:
Waste must be disposed of in accordance with federal, state and local environmental control regulations.

Section 14: Transport Information

DOT Classification: CLASS 3: Flammable liquid.

Identification: : Toluene UNNA: 1294 PG: II

Special Provisions for Transport: Not available.

Section 15: Other Regulatory Information

Federal and State Regulations:
California prop. 65: This product contains the following ingredients for which the State of California has found to cause cancer, birth defects or other reproductive harm, which would require a warning under the statute: Toluene California prop. 65 (no significant risk level): Toluene: 7 mg/day (value) California prop. 65 (acceptable daily intake level): Toluene: 7 mg/day (value) California prop. 65: This product contains the following ingredients for which the State of California has found to cause birth defects which would require a warning under the statute: Toluene Connecticut hazardous material survey.: Toluene Illinois

toxic substances disclosure to employee act: Toluene Illinois chemical safety act: Toluene New York release reporting list: Toluene Rhode Island RTK hazardous substances: Toluene Pennsylvania RTK: Toluene Florida: Toluene Minnesota: Toluene Michigan critical material: Toluene Massachusetts RTK: Toluene Massachusetts spill list: Toluene New Jersey: Toluene New Jersey spill list: Toluene Louisiana spill reporting: Toluene California Director's List of Hazardous Substances.: Toluene TSCA 8(b) inventory: Toluene TSCA 8(d) H and S data reporting: Toluene: Effective date: 10/04/82; Sunset Date: 10/0/92 SARA 313 toxic chemical notification and release reporting: Toluene CERCLA: Hazardous substances.: Toluene: 1000 lbs. (453.6 kg)

Other Regulations:
OSHA: Hazardous by definition of Hazard Communication Standard (29 CFR 1910.1200). EINECS: This product is on the European Inventory of Existing Commercial Chemical Substances.

Other Classifications:

WHMIS (Canada):
CLASS B-2: Flammable liquid with a flash point lower than 37.8°C (100°F). CLASS D-2A: Material causing other toxic effects (VERY TOXIC).

DSCL (EEC):
R11- Highly flammable. R20- Harmful by inhalation. S16- Keep away from sources of ignition - No smoking. S25- Avoid contact with eyes. S29- Do not empty into drains. S33- Take precautionary measures against static discharges.

HMIS (U.S.A.):

Health Hazard: 2

Fire Hazard: 3

Reactivity: 0

Personal Protection: h

National Fire Protection Association (U.S.A.):

Health: 2

Flammability: 3

Reactivity: 0

Specific hazard:

Protective Equipment:
Gloves. Lab coat. Vapor respirator. Be sure to use an approved/certified respirator or equivalent. Wear appropriate respirator when ventilation is inadequate. Splash goggles.

Section 16: Other Information

References: Not available.

Other Special Considerations: Not available.

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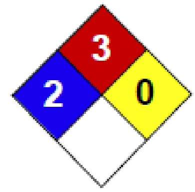

Health	2
Fire	3
Reactivity	0
Personal Protection	H

Material Safety Data Sheet
p-Xylene MSDS

Section 1: Chemical Product and Company Identification

Product Name: p-Xylene

Catalog Codes: SLX1120

CAS#: 106-42-3

RTECS: ZE2625000

TSCA: TSCA 8(b) inventory: p-Xylene

CI#: Not applicable.

Synonym: p-Methyltoluene

Chemical Name: 1,4-Dimethylbenzene

Chemical Formula: C6H4(CH3)2

Contact Information:

Sciencelab.com, Inc.
14025 Smith Rd.
Houston, Texas 77396

US Sales: **1-800-901-7247**
International Sales: **1-281-441-4400**

Order Online: ScienceLab.com

CHEMTREC (24HR Emergency Telephone), call:
1-800-424-9300

International CHEMTREC, call: 1-703-527-3887

For non-emergency assistance, call: 1-281-441-4400

Section 2: Composition and Information on Ingredients

Composition:

Name	CAS #	% by Weight
{p-}Xylene	106-42-3	100

Toxicological Data on Ingredients: p-Xylene: ORAL (LD50): Acute: 5000 mg/kg [Rat.]. DERMAL (LD50): Acute: 12400 mg/kg [Rabbit.]. VAPOR (LC50): Acute: 4550 ppm 4 hour(s) [Rat].

Section 3: Hazards Identification

Potential Acute Health Effects:
Very hazardous in case of skin contact (irritant), of eye contact (irritant). Slightly hazardous in case of skin contact (permeator), of ingestion, of inhalation. Inflammation of the eye is characterized by redness, watering, and itching. Skin inflammation is characterized by itching, scaling, reddening, or, occasionally, blistering.

Potential Chronic Health Effects:
Hazardous in case of skin contact (irritant), of eye contact (irritant). Slightly hazardous in case of skin contact (permeator), of ingestion, of inhalation. CARCINOGENIC EFFECTS: Not available. MUTAGENIC EFFECTS: Not available. TERATOGENIC EFFECTS: Not available. DEVELOPMENTAL TOXICITY: Not available. The substance is toxic to blood, kidneys, the nervous system, liver. Repeated or prolonged exposure to the substance can produce target organs damage.

Section 4: First Aid Measures

Eye Contact: Check for and remove any contact lenses. Do not use an eye ointment. Seek medical attention.

Skin Contact:
After contact with skin, wash immediately with plenty of water. Gently and thoroughly wash the contaminated skin with running water and non-abrasive soap. Be particularly careful to clean folds, crevices, creases and groin. Cover the irritated skin with an emollient. If irritation persists, seek medical attention. Wash contaminated clothing before reusing.

Serious Skin Contact:
Wash with a disinfectant soap and cover the contaminated skin with an anti-bacterial cream. Seek immediate medical attention.

Inhalation: Allow the victim to rest in a well ventilated area. Seek immediate medical attention.

Serious Inhalation: Not available.

Ingestion:
Do not induce vomiting. Examine the lips and mouth to ascertain whether the tissues are damaged, a possible indication that the toxic material was ingested; the absence of such signs, however, is not conclusive. Loosen tight clothing such as a collar, tie, belt or waistband. If the victim is not breathing, perform mouth-to-mouth resuscitation. Seek immediate medical attention.

Serious Ingestion: Not available.

Section 5: Fire and Explosion Data

Flammability of the Product: Flammable.

Auto-Ignition Temperature: 527°C (980.6°F)

Flash Points: CLOSED CUP: 25°C (77°F). OPEN CUP: 28.9°C (84°F) (Cleveland).

Flammable Limits: LOWER: 1.1% UPPER: 7%

Products of Combustion: These products are carbon oxides (CO, CO2).

Fire Hazards in Presence of Various Substances: Highly flammable in presence of open flames and sparks, of heat.

Explosion Hazards in Presence of Various Substances:
Risks of explosion of the product in presence of mechanical impact: Not available. Risks of explosion of the product in presence of static discharge: Not available.

Fire Fighting Media and Instructions:
Flammable liquid, insoluble in water. SMALL FIRE: Use DRY chemical powder. LARGE FIRE: Use water spray or fog. Cool containing vessels with water jet in order to prevent pressure build-up, autoignition or explosion.

Special Remarks on Fire Hazards:
Explosive in the form of vapor when exposed to heat or flame. Vapor may travel considerable distance to source of ignition and flash back. When heated to decomposition it emits acrid smoke and irritating fumes.

Special Remarks on Explosion Hazards: Not available.

Section 6: Accidental Release Measures

Small Spill: Absorb with an inert material and put the spilled material in an appropriate waste disposal.

Large Spill:
Toxic flammable liquid, insoluble or very slightly soluble in water. Keep away from heat. Keep away from sources of ignition. Stop leak if without risk. Absorb with DRY earth, sand or other non-combustible material. Do not get water inside container. Do not touch spilled material. Prevent entry into sewers, basements or confined areas; dike if needed. Eliminate all ignition sources. Call for assistance on disposal. Be careful that the product is not present at a concentration level above TLV. Check TLV on the MSDS and with local authorities.

Section 7: Handling and Storage

Precautions:
Keep away from heat. Keep away from sources of ignition. Ground all equipment containing material. Do not ingest. Do not breathe gas/fumes/ vapour/spray. If ingested, seek medical advice immediately and show the container or the label. Avoid contact with skin and eyes Keep away from incompatibles such as oxidizing agents.

Storage:
Flammable materials should be stored in a separate safety storage cabinet or room. Keep away from heat. Keep away from sources of ignition. Keep container tightly closed. Keep in a cool, well-ventilated place. Ground all equipment containing material. A refrigerated room would be preferable for materials with a flash point lower than 37.8°C (100°F).

Section 8: Exposure Controls/Personal Protection

Engineering Controls:
Provide exhaust ventilation or other engineering controls to keep the airborne concentrations of vapors below their respective threshold limit value. Ensure that eyewash stations and safety showers are proximal to the work-station location.

Personal Protection:
Splash goggles. Lab coat. Vapor respirator. Be sure to use an approved/certified respirator or equivalent. Gloves.

Personal Protection in Case of a Large Spill:
Splash goggles. Full suit. Vapor respirator. Boots. Gloves. A self contained breathing apparatus should be used to avoid inhalation of the product. Suggested protective clothing might not be sufficient; consult a specialist BEFORE handling this product.

Exposure Limits:
TWA: 100 STEL: 150 (ppm) from ACGIH (TLV) TWA: 434 STEL: 651 (mg/m3) from ACGIHConsult local authorities for acceptable exposure limits.

Section 9: Physical and Chemical Properties

Physical state and appearance: Liquid. (Liquid.)

Odor: Not available.

Taste: Not available.

Molecular Weight: 106.17 g/mole

Color: Colorless.

pH (1% soln/water): Not applicable.

Boiling Point: 138°C (280.4°F)

Melting Point: 12°C (53.6°F)

Critical Temperature: Not available.

Specific Gravity: 0.86 (Water = 1)

Vapor Pressure: 9 mm of Hg (@ 20°C)

Vapor Density: 3.7 (Air = 1)

Volatility: Not available.

Odor Threshold: 0.62 ppm

Water/Oil Dist. Coeff.: Not available.

Ionicity (in Water): Not available.

Dispersion Properties: See solubility in water, methanol, diethyl ether.

Solubility:
Easily soluble in methanol, diethyl ether. Insoluble in cold water, hot water.

Section 10: Stability and Reactivity Data

Stability: The product is stable.

Instability Temperature: Not available.

Conditions of Instability: Not available.

Incompatibility with various substances: Reactive with oxidizing agents.

Corrosivity: Non-corrosive in presence of glass.

Special Remarks on Reactivity: Not available.

Special Remarks on Corrosivity: Not available.

Polymerization: No.

Section 11: Toxicological Information

Routes of Entry: Eye contact.

Toxicity to Animals:
WARNING: THE LC50 VALUES HEREUNDER ARE ESTIMATED ON THE BASIS OF A 4-HOUR EXPOSURE. Acute oral toxicity (LD50): 5000 mg/kg [Rat.]. Acute dermal toxicity (LD50): 12400 mg/kg [Rabbit.]. Acute toxicity of the vapor (LC50): 4550 ppm 4 hour(s) [Rat].

Chronic Effects on Humans: The substance is toxic to blood, kidneys, the nervous system, liver.

Other Toxic Effects on Humans:
Very hazardous in case of skin contact (irritant). Slightly hazardous in case of skin contact (permeator), of ingestion, of inhalation.

Special Remarks on Toxicity to Animals: Not available.

Special Remarks on Chronic Effects on Humans:
0347 Animal: embryotoxic, foetotoxic, passes through the placental barrier. 0900 Detected in maternal milk in human. Narcotic effect; may cause nervous system disturbances.

Special Remarks on other Toxic Effects on Humans: Material is irritating to mucous membranes and upper respiratory tract.

Section 12: Ecological Information

Ecotoxicity: Not available.

BOD5 and COD: Not available.

Products of Biodegradation:
Possibly hazardous short term degradation products are not likely. However, long term degradation products may arise.

Toxicity of the Products of Biodegradation: The products of degradation are more toxic.

Special Remarks on the Products of Biodegradation: Not available.

Section 13: Disposal Considerations

Waste Disposal:

Section 14: Transport Information

DOT Classification: Class 3: Flammable liquid.

Identification: : Xylene : UN1307 PG: III

Special Provisions for Transport: Not available.

Section 15: Other Regulatory Information

Federal and State Regulations:
Pennsylvania RTK: p-Xylene Florida: p-Xylene Massachusetts RTK: p-Xylene New Jersey: p-Xylene TSCA 8(b) inventory: p-Xylene SARA 313 toxic chemical notification and release reporting: p-Xylene CERCLA: Hazardous substances.: p-Xylene

Other Regulations: OSHA: Hazardous by definition of Hazard Communication Standard (29 CFR 1910.1200).

Other Classifications:

WHMIS (Canada):
CLASS B-2: Flammable liquid with a flash point lower than 37.8°C (100°F). CLASS D-2B: Material causing other toxic effects (TOXIC).

DSCL (EEC):
R10- Flammable. R38- Irritating to skin. R41- Risk of serious damage to eyes. R48/20- Harmful: danger of serious damage to health by prolonged exposure through inhalation.

HMIS (U.S.A.):

Health Hazard: 2

Fire Hazard: 3

Reactivity: 0

Personal Protection: h

National Fire Protection Association (U.S.A.):

Health: 2

Flammability: 3

Reactivity: 0

Specific hazard:

Protective Equipment:
Gloves. Lab coat. Vapor respirator. Be sure to use an approved/certified respirator or equivalent. Wear appropriate respirator when ventilation is inadequate. Splash goggles.

Section 16: Other Information

References:
-Hawley, G.G.. The Condensed Chemical Dictionary, 11e ed., New York N.Y., Van Nostrand Reinold, 1987. -Material safety data sheet emitted by: la Commission de la SantÃ© et de la SÃ©curitÃ© du Travail du QuÃ©bec. -SAX, N.I. Dangerous Properties of Indutrial Materials. Toronto, Van Nostrand Reinold, 6e ed. 1984. -The Sigma-Aldrich Library of Chemical Safety Data, Edition II. -Guide de la loi et du rÃ¨glement sur le transport des marchandises dangeureuses au canada. Centre de conformitÃ© internatinal LtÃ©e. 1986.

Other Special Considerations: Not available.

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AIR PRODUCTS

MATERIAL SAFETY DATA SHEET

SECTION 1. PRODUCT IDENTIFICATION

PRODUCT NAME: **Methane** **FORMULA:** CH_4
CHEMICAL NAME: Methane, Saturated Alphatic Hydrocarbon, Alkane
SYNONYMS: Methyl Hydride, Marsh Gas, Fire Damp

MANUFACTURER: **Air Products and Chemicals, Inc.**
7201 Hamilton Boulevard
Allentown, PA 18195 - 1501

PRODUCT INFORMATION : (800) 752-1597

MSDS NUMBER: 1070 **REVISION:** 6
REVIEW DATE: July 1999 **REVISION DATE:** July 1999

SECTION 2. COMPOSITION / INFORMATION ON INGREDIENTS

Methane is packaged as pure product (>99%).

CAS NUMBER: 74-82-8

EXPOSURE LIMITS:
OSHA: None established **ACGIH:** Simple Asphyxiant **NIOSH:** None established

SECTION 3. HAZARD IDENTIFICATION

EMERGENCY OVERVIEW

Methane is a flammable, colorless, odorless, compressed gas packaged in cylinders under high pressure. It poses an immediate fire and explosion hazard when mixed with air at concentrations exceeding 5.0%. High concentrations that can cause rapid suffocation are within the flammable range and should not be entered.

EMERGENCY TELEPHONE NUMBERS
800 - 523 - 9374 in Continental U.S. , Canada and Puerto Rico
610 - 481 - 7711 outside U.S.

ACUTE POTENTIAL HEALTH EFFECTS:
ROUTES OF EXPOSURE:
EYE CONTACT: No harmful affect.
INGESTION: Not applicable
INHALATION: Methane is nontoxic. It can, however, reduce the amount of oxygen in the air necessary to support life. Exposure to oxygen-deficient atmospheres (less than 19.5 %) may produce dizziness, nausea, vomiting, loss of consciousness, and death. At very low oxygen concentrations (less than 12 %) unconsciousness and death may occur without warning. It should be noted that before suffocation could occur, the lower flammable limit for Methane in air will be exceeded; causing both an oxygen deficient and an explosive atmosphere.
SKIN CONTACT: No harmful affect.
POTENTIAL HEALTH EFFECTS OF REPEATED EXPOSURE:
ROUTE OF ENTRY: None
SYMPTOMS: None

TARGET ORGANS: None
MEDICAL CONDITIONS AGGRAVATED BY OVEREXPOSURE: None
CARCINOGENICITY: Methane is not listed as a carcinogen or potential carcinogen by NTP, IARC, or OSHA Subpart Z.

SECTION 4. FIRST AID MEASURES

EYE CONTACT: No treatment necessary.
INGESTION: Not applicable
INHALATION: Remove person to fresh air. If not breathing, administer artificial respiration. If breathing is difficult, administer oxygen. Obtain prompt medical attention.
SKIN CONTACT: No treatment necessary.
NOTES TO PHYSICIAN: Treatment of overexposure should be directed at the control of symptoms and the clinical condition.

SECTION 5. FIRE FIGHTING MEASURES

FLASH POINT:	AUTOIGNITION:	FLAMMABLE RANGE:
-306 °F (-187.8 °C)	999 °F (537 °C)	5.0% - 15%

EXTINGUISHING MEDIA: Dry chemical, carbon dioxide, or water.
SPECIAL FIRE FIGHTING INSTRUCTIONS: Evacuate all personnel from area. If possible, without risk, shut off source of methane, then fight fire according to types of materials burning. Extinguish fire only if gas flow can be stopped. This will avoid possible accumulation and re-ignition of a flammable gas mixture. Keep adjacent cylinders cool by spraying with large amounts of water until the fire burns itself out. Self-contained breathing apparatus (SCBA) may be required.

UNUSUAL FIRE AND EXPLOSION HAZARDS: Most cylinders are designed to vent contents when exposed to elevated temperatures. Pressure in a cylinder can build up due to heat and it may rupture if pressure relief devices should fail to function.
HAZARDOUS COMBUSTION PRODUCTS: Carbon monoxide

SECTION 6. ACCIDENTAL RELEASE MEASURES

STEPS TO BE TAKEN IF MATERIAL IS RELEASED OR SPILLED: Evacuate immediate area. Eliminate any possible sources of ignition, and provide maximum explosion-proof ventilation. Use a flammable gas meter (explosimeter) calibrated for Methane to monitor concentration. Never enter an area where Methane concentration is greater than 1.0% (which is 20% of the lower flammable limit). An immediate fire and explosion hazard exists when atmospheric Methane concentration exceeds 5.0%. Use appropriate protective equipment (SCBA and fire resistant suit). Shut off source of leak if possible. Isolate any leaking cylinder. If leak is from container, pressure relief device or its valve, contact your supplier. If the leak is in the user's system, close the cylinder valve, safely vent the pressure, and purge with an inert gas before attempting repairs.

SECTION 7. STORAGE AND HANDLING

STORAGE: Store cylinders in a well-ventilated, secure area, protected from the weather. Cylinders should be stored upright with valve outlet seals and valve protection caps in place. There should be no sources of ignition. All electrical equipment should be explosion-proof in the storage areas. Storage areas must meet National Electrical Codes for class 1 hazardous areas. Flammable storage areas must be separated from oxygen and other oxidizers by a minimum distance of 20 ft. or by a barrier of non-combustible material at least 5 ft. high having a fire resistance rating of at least _ hour. Post "No Smoking or Open Flames" signs in the storage or use areas. Do not allow storage temperature to exceed 125 °F (52 °C). Storage should be away from heavily traveled areas and emergency exits. Full and empty cylinders should be segregated. Use a first-in first-out inventory system to prevent full containers from being stored for long periods of time.

HANDLING: Do not drag, roll, slide or drop cylinder. Use a suitable hand truck designed for cylinder movement. Never attempt to lift a cylinder by its cap. Secure cylinders at all times while in use. Use a pressure reducing regulator to safely discharge gas from cylinder. Use a check valve to prevent reverse flow into cylinder. Never apply flame or localized heat directly to any part of the cylinder. Do not allow any part of the cylinder to exceed 125 °F (52 °C). Use piping and equipment adequately designed to withstand pressures to be encountered. Once cylinder has been connected to properly purged and inerted process, open cylinder valve slowly and carefully. If user experiences any difficulty operating cylinder valve, discontinue use and contact supplier. Never insert an object (e.g., wrench, screwdriver, etc.) into valve cap openings. Doing so may damage valve causing a leak to occur. Use an adjustable strap-wrench to remove over-tight or rusted caps. All piped systems and associated equipment must be grounded. Electrical equipment should be non-sparking or explosion-proof.

SPECIAL PRECAUTIONS: Always store and handle compressed gas cylinders in accordance with Compressed Gas Association, Inc. (telephone 703-412-0900) pamphlet CGA P-1, *Safe Handling of Compressed Gases in Containers*. Local regulations may require specific equipment for storage or use.

SECTION 8. EXPOSURE CONTROLS/PERSONAL PROTECTION

ENGINEERING CONTROLS:

VENTILATION: Provide adequate natural or explosion-proof ventilation to prevent accumulation of gas concentrations above 1.0% Methane (20% of LEL).

RESPIRATORY PROTECTION:

Emergency Use: Do not enter areas where Methane concentration is greater than 1.0% (20% of the LEL). Exposure to concentrations below 1.0% do not require respiratory protection.

EYE PROTECTION: Safety glasses and/or face shield.
SKIN PROTECTION: Leather gloves for handling cylinders. Fire resistant suit and gloves in emergency situations.
OTHER PROTECTIVE EQUIPMENT: Safety shoes are recommended when handling cylinders.

SECTION 9. PHYSICAL AND CHEMICAL PROPERTIES

APPEARANCE, ODOR AND STATE: Colorless, odorless, flammable gas.
MOLECULAR WEIGHT: 16.04
BOILING POINT (1 atm): -258.7 °F (-161.5 °C)
SPECIFIC GRAVITY (Air = 1): 0.554
FREEZING POINT / MELTING POINT: -296. 5 °F (-182.5 °C)
VAPOR PRESSURE (At 70 _F (21.1 _C)): Permanent, noncondensable gas.
GAS DENSITY (At 70 _F (21.1 _C) and 1 atm): 0.042 lb/ft^3
SOLUBILITY IN WATER (vol/vol): 3.3 ml gas / 100 ml

SECTION 10. STABILITY AND REACTIVITY

CHEMICAL STABILITY: Stable
CONDITIONS TO AVOID: Cylinders should not be exposed to temperatures in excess of 125 °F (52 °C).
INCOMPATIBILITY (Materials to Avoid): Oxygen, Halogens and Oxidizers
REACTIVITY:

A) **HAZARDOUS DECOMPOSITION PRODUCTS:** None
B) **HAZARDOUS POLYMERIZATION:** Will not occur

SECTION 11. TOXICOLOGICAL INFORMATION

LC_{50} (Inhalation): Not applicable. Simple asphyxiant.
LD_{50} (Oral): Not applicable
LD_{50} (Dermal): Not applicable

SKIN CORROSIVITY: Methane is not corrosive to the skin.
ADDITIONAL NOTES: None

SECTION 12. ECOLOGICAL INFORMATION

AQUATIC TOXICITY: Not determined
MOBILITY: Not determined
PERSISTENCE AND BIODEGRADABILITY: Not determined
POTENTIAL TO BIOACCUMULATE: Not determined
REMARKS: This product does not contain any Class I or Class II ozone depleting chemicals.

SECTION 13. DISPOSAL CONSIDERATIONS

UNUSED PRODUCT / EMPTY CONTAINER: Return container and unused product to supplier. Do not attempt to dispose of residual or unused quantities.

DISPOSAL INFORMATION: Residual product in the system may be burned if a suitable burning unit (flair incinerator) is available on site. This shall be done in accordance with federal, state, and local regulations. Wastes containing this material may be classified by EPA as hazardous waste by characteristic (i.e., Ignitability, Corrosivity, Toxicity, Reactivity). Waste streams must be characterized by the user to meet federal, state, and local requirements.

SECTION 14. TRANSPORT INFORMATION

DOT SHIPPING NAME: Methane, compressed
HAZARD CLASS: 2.1
IDENTIFICATION NUMBER: UN1971
SHIPPING LABEL(s): Flammable gas
PLACARD (When required): Flammable gas

SPECIAL SHIPPING INFORMATION: Cylinders should be transported in a secure upright position in a well-ventilated truck. Never transport in passenger compartment of a vehicle. Ensure cylinder valve is properly closed, valve outlet cap has been reinstalled, and valve protection cap is secured before shipping cylinder.

CAUTION: Compressed gas cylinders shall not be refilled except by qualified producers of compressed gases. Shipment of a compressed gas cylinder which has not been filled by the owner or with the owner's written consent is a violation of Federal law (49 CFR 173.301).

NORTH AMERICAN EMERGENCY RESPONSE GUIDEBOOK NUMBER (NAERG #): 115

SECTION 15. REGULATORY INFORMATION

U.S. FEDERAL REGULATIONS:

EPA - ENVIRONMENTAL PROTECTION AGENCY

CERCLA: Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (40 CFR Parts 117 and 302)

Reportable Quantity (RQ): None

SARA TITLE III: Superfund Amendment and Reauthorization Act

SECTIONS 302/304: Emergency Planning and Notification (40 CFR Part 355)

Extremely Hazardous Substances: Methane is not listed.
Threshold Planning Quantity (TPQ): None
Reportable Quantity (RQ): None

SECTIONS 311/312: Hazardous Chemical Reporting (40 CFR Part 370)

IMMEDIATE HEALTH:	Yes	PRESSURE:	Yes
DELAYED HEALTH:	No	REACTIVITY:	No
		FIRE:	Yes

SECTION 313: Toxic Chemical Release Reporting (40 CFR Part 372)

Methane does not require reporting under Section 313.

CLEAN AIR ACT:
SECTION 112 (r): Risk Management Programs for Chemical Accidental Release
(40 CFR PART 68)
Methane is listed as a regulated substance.
Threshold Planning Quantity (TPQ): 10,000 lbs

TSCA: Toxic Substance Control Act
Methane is listed on the TSCA inventory.

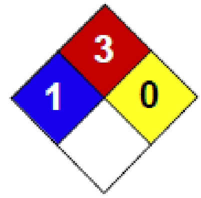
OSHA - OCCUPATIONAL SAFETY AND HEALTH ADMINISTRATION:
29 CFR Part 1910.119: Process Safety Management of Highly Hazardous Chemicals
Methane is not listed in Appendix A as a highly hazardous chemical. However, any process that involves a flammable gas on site in one location, in quantities of 10,000 pounds
(4,553 kg) or greater is covered under this regulation unless it is used as fuel.

STATE REGULATIONS:
CALIFORNIA:
Proposition 65: This product is not a listed substance which the State of California requires warning under this statute.

SECTION 16. OTHER INFORMATION

NFPA RATINGS:		**HMIS RATINGS:**	
HEALTH:	= 1	HEALTH:	= 0
FLAMMABILITY:	= 4	FLAMMABILITY:	= 4
REACTIVITY:	= 0	REACTIVITY:	= 0
SPECIAL:	= SA*		

*SA denotes "Simple Asphyxiant" per Compressed Gas Association recommendation.



Health	2
Fire	3
Reactivity	0
Personal Protection	H

Material Safety Data Sheet
Methyl alcohol MSDS

Section 1: Chemical Product and Company Identification

Product Name: Methyl alcohol

Catalog Codes: SLM3064, SLM3952

CAS#: 67-56-1

RTECS: PC1400000

TSCA: TSCA 8(b) inventory: Methyl alcohol

CI#: Not applicable.

Synonym: Wood alcohol, Methanol; Methylol; Wood Spirit; Carbinol

Chemical Name: Methanol

Chemical Formula: CH3OH

Contact Information:

Sciencelab.com, Inc.
14025 Smith Rd.
Houston, Texas 77396

US Sales: **1-800-901-7247**
International Sales: **1-281-441-4400**

Order Online: ScienceLab.com

CHEMTREC (24HR Emergency Telephone), call:
1-800-424-9300

International CHEMTREC, call: 1-703-527-3887

For non-emergency assistance, call: 1-281-441-4400

Section 2: Composition and Information on Ingredients

Composition:

Name	CAS #	% by Weight
Methyl alcohol	67-56-1	100

Toxicological Data on Ingredients: Methyl alcohol: ORAL (LD50): Acute: 5628 mg/kg [Rat]. DERMAL (LD50): Acute: 15800 mg/kg [Rabbit]. VAPOR (LC50): Acute: 64000 ppm 4 hours [Rat].

Section 3: Hazards Identification

Potential Acute Health Effects:
Hazardous in case of skin contact (irritant), of eye contact (irritant), of ingestion, of inhalation. Slightly hazardous in case of skin contact (permeator). Severe over-exposure can result in death.

Potential Chronic Health Effects:
Slightly hazardous in case of skin contact (sensitizer). CARCINOGENIC EFFECTS: Not available. MUTAGENIC EFFECTS: Mutagenic for mammalian somatic cells. Mutagenic for bacteria and/or yeast. TERATOGENIC EFFECTS: Classified POSSIBLE for human. DEVELOPMENTAL TOXICITY: Not available. The substance is toxic to eyes. The substance may be toxic to blood, kidneys, liver, brain, peripheral nervous system, upper respiratory tract, skin, central nervous system (CNS), optic nerve. Repeated or prolonged exposure to the substance can produce target organs damage. Repeated exposure to a highly toxic material may produce general deterioration of health by an accumulation in one or many human organs.

Section 4: First Aid Measures

Eye Contact:
Check for and remove any contact lenses. Immediately flush eyes with running water for at least 15 minutes, keeping eyelids open. Cold water may be used. Get medical attention.

Skin Contact:
In case of contact, immediately flush skin with plenty of water for at least 15 minutes while removing contaminated clothing and shoes. Cover the irritated skin with an emollient. Cold water may be used.Wash clothing before reuse. Thoroughly clean shoes before reuse. Get medical attention immediately.

Serious Skin Contact:
Wash with a disinfectant soap and cover the contaminated skin with an anti-bacterial cream. Seek immediate medical attention.

Inhalation:
If inhaled, remove to fresh air. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. Get medical attention immediately.

Serious Inhalation:
Evacuate the victim to a safe area as soon as possible. Loosen tight clothing such as a collar, tie, belt or waistband. If breathing is difficult, administer oxygen. If the victim is not breathing, perform mouth-to-mouth resuscitation. WARNING: It may be hazardous to the person providing aid to give mouth-to-mouth resuscitation when the inhaled material is toxic, infectious or corrosive. Seek immediate medical attention.

Ingestion:
If swallowed, do not induce vomiting unless directed to do so by medical personnel. Never give anything by mouth to an unconscious person. Loosen tight clothing such as a collar, tie, belt or waistband. Get medical attention immediately.

Serious Ingestion: Not available.

Section 5: Fire and Explosion Data

Flammability of the Product: Flammable.

Auto-Ignition Temperature: 464°C (867.2°F)

Flash Points: CLOSED CUP: 12°C (53.6°F). OPEN CUP: 16°C (60.8°F).

Flammable Limits: LOWER: 6% UPPER: 36.5%

Products of Combustion: These products are carbon oxides (CO, CO_2).

Fire Hazards in Presence of Various Substances:
Highly flammable in presence of open flames and sparks, of heat. Non-flammable in presence of shocks.

Explosion Hazards in Presence of Various Substances:
Risks of explosion of the product in presence of mechanical impact: Not available. Explosive in presence of open flames and sparks, of heat.

Fire Fighting Media and Instructions:
Flammable liquid, soluble or dispersed in water. SMALL FIRE: Use DRY chemical powder. LARGE FIRE: Use alcohol foam, water spray or fog.

Special Remarks on Fire Hazards:
Explosive in the form of vapor when exposed to heat or flame. Vapor may travel considerable distance to source of ignition and flash back. When heated to decomposition, it emits acrid smoke and irritating fumes. CAUTION: MAY BURN WITH NEAR INVISIBLE FLAME

Special Remarks on Explosion Hazards:
Forms an explosive mixture with air due to its low flash point. Explosive when mixed with Choroform + sodium methoxide and diethyl zinc. It boils violently and explodes.

Section 6: Accidental Release Measures

Small Spill:
Dilute with water and mop up, or absorb with an inert dry material and place in an appropriate waste disposal container.

Large Spill:
Flammable liquid. Poisonous liquid. Keep away from heat. Keep away from sources of ignition. Stop leak if without risk. Absorb with DRY earth, sand or other non-combustible material. Do not get water inside container. Do not touch spilled material. Use water spray to reduce vapors. Prevent entry into sewers, basements or confined areas; dike if needed. Call for assistance on disposal. Be careful that the product is not present at a concentration level above TLV. Check TLV on the MSDS and with local authorities.

Section 7: Handling and Storage

Precautions:
Keep locked up.. Keep away from heat. Keep away from sources of ignition. Ground all equipment containing material. Do not ingest. Do not breathe gas/fumes/ vapor/spray. Wear suitable protective clothing. In case of insufficient ventilation, wear suitable respiratory equipment. If ingested, seek medical advice immediately and show the container or the label. Avoid contact with skin and eyes. Keep away from incompatibles such as oxidizing agents, metals, acids.

Storage:
Store in a segregated and approved area. Keep container in a cool, well-ventilated area. Keep container tightly closed and sealed until ready for use. Avoid all possible sources of ignition (spark or flame).

Section 8: Exposure Controls/Personal Protection

Engineering Controls:
Provide exhaust ventilation or other engineering controls to keep the airborne concentrations of vapors below their respective threshold limit value. Ensure that eyewash stations and safety showers are proximal to the work-station location.

Personal Protection:
Splash goggles. Lab coat. Vapor respirator. Be sure to use an approved/certified respirator or equivalent. Gloves.

Personal Protection in Case of a Large Spill:
Splash goggles. Full suit. Vapor respirator. Boots. Gloves. A self contained breathing apparatus should be used to avoid inhalation of the product. Suggested protective clothing might not be sufficient; consult a specialist BEFORE handling this product.

Exposure Limits:
TWA: 200 from OSHA (PEL) [United States] TWA: 200 STEL: 250 (ppm) from ACGIH (TLV) [United States] [1999] STEL: 250 from NIOSH [United States] TWA: 200 STEL: 250 (ppm) from NIOSH SKIN TWA: 200 STEL: 250 (ppm) [Canada] Consult local authorities for acceptable exposure limits.

Section 9: Physical and Chemical Properties

Physical state and appearance: Liquid.

Odor: Alcohol like. Pungent when crude.

Taste: Not available.

Molecular Weight: 32.04 g/mole

Color: Colorless.

pH (1% soln/water): Not available.

Boiling Point: 64.5°C (148.1°F)

Melting Point: -97.8°C (-144°F)

Critical Temperature: 240°C (464°F)

Specific Gravity: 0.7915 (Water = 1)

Vapor Pressure: 12.3 kPa (@ 20°C)

Vapor Density: 1.11 (Air = 1)

Volatility: Not available.

Odor Threshold: 100 ppm

Water/Oil Dist. Coeff.: The product is more soluble in water; log(oil/water) = -0.8

Ionicity (in Water): Non-ionic.

Dispersion Properties: See solubility in water.

Solubility: Easily soluble in cold water, hot water.

Section 10: Stability and Reactivity Data

Stability: The product is stable.

Instability Temperature: Not available.

Conditions of Instability: Heat, ingnition sources, incompatible materials

Incompatibility with various substances: Reactive with oxidizing agents, metals, acids.

Corrosivity: Non-corrosive in presence of glass.

Special Remarks on Reactivity:
Can react vigorously with oxidizers. Violent reaction with alkyl aluminum salts, acetyl bromide, chloroform + sodium methoxide, chromic anhydride, cyanuirc chlorite, lead perchlorate, phosphorous trioxide, nitric acid. Exothermic reaction with sodium hydroxide + chloroform. Incompatible with beryllium dihydride, metals (potassium and magnesium), oxidants (barium perchlorate, bromine, sodium hypochlorite, chlorine, hydrogen peroxide), potassium tert-butoxide, carbon tetrachloride, alkali metals, metals (aluminum, potassium magnesium, zinc), and dichlormethane. Rapid autocatalytic dissolution of aluminum, magnesium or zinc in 9:1 methanol + carbon tetrachloride - sufficiently vigorous to be rated as potentially hazardous. May attack some plastics, rubber, and coatings.

Special Remarks on Corrosivity: Not available.

Polymerization: Will not occur.

Section 11: Toxicological Information

Routes of Entry: Absorbed through skin. Eye contact. Inhalation. Ingestion.

Toxicity to Animals:
WARNING: THE LC50 VALUES HEREUNDER ARE ESTIMATED ON THE BASIS OF A 4-HOUR EXPOSURE. Acute oral toxicity (LD50): 5628 mg/kg [Rat]. Acute dermal toxicity (LD50): 15800 mg/kg [Rabbit]. Acute toxicity of the vapor (LC50): 64000 4 hours [Rat].

Chronic Effects on Humans:
MUTAGENIC EFFECTS: Mutagenic for mammalian somatic cells. Mutagenic for bacteria and/or yeast. TERATOGENIC EFFECTS: Classified POSSIBLE for human. Causes damage to the following organs: eyes. May cause damage to the following organs: blood, kidneys, liver, brain, peripheral nervous system, upper respiratory tract, skin, central nervous system (CNS), optic nerve.

Other Toxic Effects on Humans:
Hazardous in case of skin contact (irritant), of ingestion, of inhalation. Slightly hazardous in case of skin contact (permeator).

Special Remarks on Toxicity to Animals: Not available.

Special Remarks on Chronic Effects on Humans:

Passes through the placental barrier. May affect genetic material. May cause birth defects and adverse reproductive effects(paternal and maternal effects and fetotoxicity) based on animal studies.

Special Remarks on other Toxic Effects on Humans:

Section 12: Ecological Information

Ecotoxicity: Ecotoxicity in water (LC50): 29400 mg/l 96 hours [Fathead Minnow].

BOD5 and COD: Not available.

Products of Biodegradation:
Possibly hazardous short term degradation products are not likely. However, long term degradation products may arise.

Toxicity of the Products of Biodegradation: The products of degradation are less toxic than the product itself.

Special Remarks on the Products of Biodegradation:
Methanol in water is rapidly biodegraded and volatilized. Aquatic hydrolysis, oxidation, photolysis, adsorption to sediment, and bioconcentration are not significant fate processes. The half-life of methanol in surfact water ranges from 24 hrs. to 168 hrs. Based on its vapor pressure, methanol exists almost entirely in the vapor phase in the ambient atmosphere. It is degraded by reaction with photochemically produced hydroxyl radicals and has an estimated half-life of 17.8 days. Methanol is physically removed from air by rain due to its solubility. Methanol can react with NO2 in pollulted to form methyl nitrate. The half-life of methanol in air ranges from 71 hrs. (3 days) to 713 hrs. (29.7 days) based on photooxidation half-life in air.

Section 13: Disposal Considerations

Waste Disposal:
Waste must be disposed of in accordance with federal, state and local environmental control regulations.

Section 14: Transport Information

DOT Classification: CLASS 3: Flammable liquid.

Identification: : Methyl alcohol UNNA: 1230 PG: II

Special Provisions for Transport: Not available.

Section 15: Other Regulatory Information

Federal and State Regulations:
Connecticut hazardous material survey.: Methyl alcohol Illinois toxic substances disclosure to employee act: Methyl alcohol Illinois chemical safety act: Methyl alcohol New York release reporting list: Methyl alcohol Rhode Island RTK hazardous substances: Methyl alcohol Pennsylvania RTK: Methyl alcohol Minnesota: Methyl alcohol Massachusetts RTK: Methyl alcohol Massachusetts spill list: Methyl alcohol New Jersey: Methyl alcohol New Jersey spill list: Methyl alcohol Louisiana spill reporting: Methyl alcohol California Directors List of Hazardous Substances (8CCR 339): Methyl alcohol Tennesse Hazardous Right to Know : Methyl alcohol TSCA 8(b) inventory: Methyl alcohol SARA 313 toxic chemical notification and release reporting: Methyl alcohol CERCLA: Hazardous substances.: Methyl alcohol: 5000 lbs. (2268 kg)

Other Regulations:
OSHA: Hazardous by definition of Hazard Communication Standard (29 CFR 1910.1200). EINECS: This product is on the European Inventory of Existing Commercial Chemical Substances.

Other Classifications:

WHMIS (Canada):
CLASS B-2: Flammable liquid with a flash point lower than 37.8°C (100°F). CLASS D-1B: Material causing immediate and serious toxic effects (TOXIC). CLASS D-2A: Material causing other toxic effects (VERY TOXIC). Class D-2B: Material causing other toxic effects (TOXIC).

DSCL (EEC):
R11- Highly flammable. R23/24/25- Toxic by inhalation, in contact with skin and if swallowed. R39- Danger of very serious irreversible effects. R39/23/24/25- Toxic: danger of very serious irreversible effects through inhalation, in contact with skin and if swallowed. S7- Keep container tightly closed. S16- Keep away from sources of ignition - No smoking. S36/37- Wear suitable protective clothing and gloves. S45- In case of accident or if you feel unwell, seek medical advice immediately (show the label where possible).

HMIS (U.S.A.):

Health Hazard: 2

Fire Hazard: 3

Reactivity: 0

Personal Protection: h

National Fire Protection Association (U.S.A.):

Health: 1

Flammability: 3

Reactivity: 0

Specific hazard:

Protective Equipment:
Gloves. Lab coat. Vapor respirator. Be sure to use an approved/certified respirator or equivalent. Wear appropriate respirator when ventilation is inadequate. Splash goggles.

Section 16: Other Information

References:
-SAX, N.I. Dangerous Properties of Indutrial Materials. Toronto, Van Nostrand Reinold, 6e ed. 1984. -Material safety data sheet emitted by: la Commission de la SantÃ© et de la SÃ©curitÃ© du Travail du QuÃ©bec. -Hawley, G.G.. The Condensed Chemical Dictionary, 11e ed., New York N.Y., Van Nostrand Reinold, 1987. LOLI, HSDB, RTECS, HAZARDTEXT, REPROTOX databases

Other Special Considerations: Not available.

Created: 10/10/2005 08:23 PM

Last Updated: 05/21/2013 12:00 PM

Appendix D: Problem Statement

Natural Gas to BTX
(recommended by Bruce M. Vrana, DuPont)

Inexpensive natural gas in the U.S. from fracking is leading to the resurgence of the U.S. chemical industry and a wide array of new possibilities. Until now, however, there has been no economical means to convert natural gas to aromatics. Benzene, toluene and xylene (BTX) are conventionally produced by reforming naphtha in an oil refinery or by extracting them from naphtha-fed ethylene crackers. Both sources of BTX are tied to expensive crude oil.

Your company has developed a catalyst to convert natural gas to BTX, primarily to benzene. The proposed process uses a proprietary Zeolite catalyst impregnated with copper and molybdenum to form aromatics. Adding a few percent carbon dioxide in the reactor feed aids the formation of benzene.

Your team has been assembled to develop the most economic process to make benzene and/or BTX to capitalize on inexpensive natural gas. Management desires a plant to produce 1MMM lb/yr of total BTX from natural gas at your U.S. Gulf Coast site. They also desire a plant that uses this new catalyst in the most economical way. But management did not specify whether you should separate the BTX produced into one or more pure products (benzene, toluene, p-xylene [PX], etc.) as well as a mixed BTX stream as a coproduct, or whether you should just produce mixed BTX. They only want to maximize the NPV of the venture, and leave the decision of the most economic products up to you.

You will need to focus on the process to make BTX, not the process to make the catalyst, which you can assume will be produced for you by a catalyst vendor.

Natural gas is available by pipeline at your plant site for $4.00/MSCF. You may assume the gas you purchase is 95% CH_4 (by volume), 4% CO_2, and 1% N_2. If desired, you may purchase CO_2 for $20/ton. Benzene can be sold for $4.50/gal. Toluene can be sold for $3.75/gal. PX can be sold for $0.70/lb. Other xylenes, if any, and any mixed BTX streams can be sold for $3.50/gal. All prices are forecasts by your marketing organization for long term average prices, expressed in 2015 dollars for the quantities needed, delivered to your site or sold from your site.

You will need to make many assumptions to complete your design, since the data you have is far from complete. State them explicitly in your report, so that management may understand the uncertainty in your design and economic projections before approving an expensive pilot plant to provide the scale-up data you need to complete the design. Test your economics to reasonable ranges of your assumptions. If there are any possible “show- stoppers” (i.e., possible fatal flaws, if one assumption is incorrect that would make the design either technically infeasible or uneconomical), these need to be clearly communicated and understood before proceeding.

The plant design should be as environmentally friendly as possible, at a minimum meeting Federal and state emissions regulations. Recover and recycle process materials to the maximum economic extent. Also, energy consumption should be minimized, to the extent economically justified. The plant design must also be controllable and safe to operate. Remember that, if the plant is approved, you will be there for the plant start-up and will have to live with whatever design decisions you have made.

Reference

U.S. Patent 8,278,237, October 2, 2012, assigned to Meidensha Corporation

Appendix E: Email Correspondences

In regards to F-101:

Sent on 2015-04-06 9:56, lfabiano wrote:
Hello Teaam:

Use this attachmnent and see page 19 for furnace costs. just use heat load.

On 2015-04-06 00:03, Alex Evans wrote:
Professor,

We were wondering if you had any ideas for our furnace as far as costing that we discussed last Thursday? We updated our furnace section this weekend so our numbers are a little different than they were last Thursday, but hopefully that won't affect too much. As a reminder, we're using a furnace to burn a purge stream for the purposes of generating heat. We decided on Thursday that the heat exchangers that occur downstream of the furnace in our model (H-401, H-402, H-403, H-404, H-405, and H-406) will be designed as a series of tubes and coils in some sort of long box next to the furnace in order to capture its heat. Right now, we have costs done for the downstream heat exchangers, so we can use those to approximate the costs of the tubes and coils, but we are missing the cost of the furnace itself. We are okay with approximating the coils as the cost of shell-and-tube exchangers (or some fraction of their bare-module cost) but we still need a price for the furnace. Can you help us with that?

The ASPEN file is attached for your reference.

Thank you!!
Alex, Sandhya, and Bruce

In regard to H-403, Storage tanks, and H-101 and H-103:

From Bruce.M.Vrana@dupont.com on 6 April, 2015 9:57AM:

No, I'm afraid you can't just divide by 8 if the capacity goes down by a factor of 8. Most equipment has some economy of scale, which means that the cost is proportional to the ratio of the capacities to some exponent. This is often called the six-tenths rule, since the exponent is often 0.6. Large boilers generally have an exponent more like 0.8 than 0.6. So the cost estimated by scaling would be (0.5/2.3)^0.8 * $10.4 = $3.1MM.

But better still, you are now at the point where you can use a packaged boiler, which would be less expensive. That would cost about $2.29MM.

Good luck.

Bruce

From: Alex Evans [mailto:alevans@seas.upenn.edu]
Sent: Monday, April 06, 2015 3:18 AM
To: VRANA, BRUCE M
Cc: Sandhya Thiyagarajan; bcha@seas.upenn.edu
Subject: Re: Heat Exchanger -- U Values

Thank you again for your help. We changed our steam generation to reduce the amount of flow through the furnace and thus are making less steam. Now, we are making 500MM BTU/hr of steam at 400 psia and 100 degrees superheat, which is about 1/8 what we were making before. What kind of price can we use for this boiler? Can we divide $10.4MM by 8?

Thank you!
Alex, Sandhya, and Bruce

On Fri, Apr 3, 2015 at 10:48 AM, <Bruce.M.Vrana@dupont.com> wrote:

Okay, hopefully I will answer all the questions you've asked, but if I've missed anything, or if you have any others, please get back to me.

For the boiler, you appear to be looking at what we normally call packaged boilers, put together in a factory and delivered. You need a large field-erected boiler, that will be built on site. You didn't specify steam pressure or superheat, so I assumed 400 psig and 100 deg F superheat, which are pretty typical values. Let me know if you need very different steam conditions and I can get the costs again. The estimated cost for a boiler making 2.3MMM Btu/hr of steam is $10.4MM. That's a lot of money, but at least it's better than 34 packaged boilers totaling $33MM. Since this is field erected, this is an installed cost, but does not include foundations, steam headers, etc.

For the big heat exchangers, well, everything is really big, even by oil refinery standards. Even with my sources, I would need 11 exchangers, each 14,800 ft2. They can actually be built bigger than that, but I think it costs more money. The total purchased equipment cost would be $2.26MM. I think a U of 150 is reasonable. You can use your heat exchanger costs if you would rather, to be consistent with your other exchanger costs. Again, I didn't know things like design pressure, so I made reasonable assumptions. The other option would be to use plate heat exchangers rather than shell and tube for the large units. That would cost $1.29MM for the service you mentioned. It might actually be less than that, because those units often get a higher heat transfer coefficient. Plate heat exchangers are not usually used in refineries or petrochemical plants, but should work just fine. These prices are purchased equipment prices and are total prices, not each.

On the storage tank, you need to be careful to get the price of a storage tank as opposed to a pressure vessel normally used in the process. Storage tanks are not designed to hold any pressure other than the hydrostatic pressure of the material inside. I estimate the cost of a 1.5MM gal tank as $521M. This is a field erected tank, so it is installed, but does not include foundation, piping, etc. These tanks can get essentially as big as you want.

All of the equipment costs I've given you are from Aspen Icarus with a cost basis in 1Q13. You'll need to escalate all of them by 2+ years to get to today.

Good luck with everything.

Bruce

On Wed, Apr 1, 2015 at 4:17 PM, Alex Evans <alevans@seas.upenn.edu> wrote:
I should mention we're having a problem costing the steam generation that we discussed yesterday as well. Again, the spreadsheets that they gave us do not go as high as we need for a boiler. We're using a "steam boiler" model in the spreadsheet (attached) which has a maximum duty of 70MM BTU/hr. For our process, we need to remove 2.3B BTU/hr, which would require 33 boilers using this maximum duty value. In your experience, is there a higher value for the maximum duty we can building into one boiler? The flow rate of the water feed stream to the boiler is almost 2MM lb/hr.

Thanks again,
Alex, Sandhya, and Bruce

On Wed, Apr 1, 2015 at 1:35 PM, Alex Evans <alevans@seas.upenn.edu> wrote:
We have this issue for more than just one heat exchanger, but it's a bigger issue on our larger streams of course. The biggest duty we have is on the scale of 2B BTU/hr. Here's the info for that heater, which is exchanging temperature between two vapors:

Q	1.90E+09	1.90E+09	BTU/hr
Tci	160	160	F
Tco	1172	1172	F
Thi	1239	1239	F
Tho	250	250	F
ΔTlm	77.94	77.94	F
U	100	150	BTU/hr-ft2-F
A	243743.29	162495.53	ft2
# Exchangers	20.31194	13.54129	
A per exchanger	11606.82	11606.82	ft2

There is no upper bound for our spreadsheet on volume, but it's designed more for smaller vessels an doesn't really scale to 1MM gallons. Since benzene is less dense than water should we increase or decrease the price for the storage tank? Or maybe just stick with the given price and adjust for 2015 prices?

Thanks again,
Alex, Sandhya, and Bruce

On Wed, Apr 1, 2015 at 11:27 AM, <Bruce.M.Vrana@dupont.com> wrote:
About the heat exchanger, can you give me more details? What is the heat duty, what are the inlet and outlet temperatures of both streams, and what LMTD do you calculate? This is a feed-effluent exchanger, right, and you may simply be trying to get too tight of a temperature approach to be economical. If you relax the LMTD a bit, it will cost you some more energy in the reactor heater, but will save you capital.

How big does your spreadsheet go for prices of storage tanks? For flexibility, typically you would want two tanks, perhaps each 1.5MM gallons, if you want 3MM gallons total storage, despite the cost penalty of having two tanks vs. one larger tank. But I don't see how you got $3.1MM for the storage tank from the PAAWWA source you sent, unless that is the total project-level investment that you've estimated separately. It looks to me like a 3MM gal welded steel tank would be $1.27MM (slide 22). That is the price you would pay the contractor to have that tank built on site and does not include foundations, piping, etc. The design of a benzene tank is not the same as for water – differences in density, materials of construction and the safety requirements for benzene, among other considerations. But that price does not seem totally out of line. It looks like that is a 2013 cost estimate, based on the date embedded in the path on the server, so you might want to escalate that to get to a 2015 price, although that will only add a few percent. Let me check my sources and see if I can give you a better figure.

Thanks.
Bruce

From: Alex Evans [mailto:alevans@seas.upenn.edu]
Sent: Wednesday, April 01, 2015 1:26 AM
To: VRANA, BRUCE M
Cc: Sandhya Thiyagarajan; bcha@seas.upenn.edu
Subject: Re: Heat Exchanger -- U Values

Mr. Vrana, we have one more question for you (for now).
We've found a source online from the Pennsylvania American Water Works Association that shows a 3MM gallon storage tank costing around $3.1MM. Do you think this price is reasonable to include in our costing estimates for our process? Also, we'd be be able to get through Thanksgiving weekend with just one of these tanks or our benzene! If we cannot use this can you suggest an alternative way to price these tanks? Our spreadsheets don't go as high as we need them to for this volume.

Thanks,
Alex, Sandhya, and Bruce

On Tue, Mar 31, 2015 at 11:37 PM, Alex Evans <alevans@seas.upenn.edu> wrote:
Mr. Vrana,

We are running into some trouble designing our heat exchangers, specifically with our transfer coefficients. When we design our exchangers, can we use a value of 150 BTU/hr-ft2-R? If we use 125 or 100 we would simply require too many exchangers due to the scale of our process (cross-heating the feed and effluent to our first reactor would require 44 exchangers using a U value of 100 BTU/hr-ft2-R, but only 17 with a U value of 150).

Thank you,
Alex, Sandhya, and Bruce

In regard to H-106:

---------- Forwarded message ----------
From: <Bruce.M.Vrana@dupont.com>
Date: Apr 6, 2015 11:56 AM
Subject: RE: Propane Refrigeration
To: <sandhya526@gmail.com>
Cc:

Wow, that is a huge refrig system. Refrig is quoted in different units – tons of refrigeration. 1 ton is the amount of heat cooling you get from 1 ton of ice melting over a 24 hour period. It is equal to 12,000 Btu/hr. Home air conditioners have usually 1 to 5 tons of refrigeration. You need nearly 17,000 tons. This is much larger than usual refrig machines – but I suspect that doesn't surprise you.

The largest refrig machines in Icarus are 3000 tons. So I estimated the cost of 6 units, each 2778 tons. This gives an estimate of $10.2MM total (not each). Again, that's the purchased price of the packaged units, and does not include foundations, piping, engineering costs, contingency, etc. Chances are you could get a custom system designed and built for a bit less than the cost of 6 smaller units, but much of the cost is just compressors and heat exchangers, so I suspect there is not much economy of scale and you will not save that much. The motor on each of the 6 compressors is 7000 hp, so you might want to cross-check against your previous electricity consumption.

Bruce

From: Sandhya Thiyagarajan [mailto:sandhya526@gmail.com]
Sent: Monday, April 06, 2015 11:17 AM
To: VRANA, BRUCE M
Subject: Propane Refrigeration

Mr. Vrana,
Thank you for all your help thus far! We really appreciate it. We just have one final costing question about a propane refrigeration unit. We have an estimate of around 75 million dollars for the unit as a capital cost and operational costs would just be the electricity. Does this estimate seem reasonable to you? Our contact was not totally confident in the number. I've included some details on the unit below. Thanks!

Flow rate: 2.4 MMlb/hr
Inlet temp: 110 F
Outlet temp: -31 F
Duty: 200 MM BTU/hr
Steam composition: Methane, BTX, naphthalene, hydrogen , CO, CO2, nitrogen

Sincerely,
Sandhya, Bruce, and Alex

In regard to the PRISM Membrane Unit:

---------- Forwarded message ----------
From: "Fair,Karin Aurora" <FAIRKA@airproducts.com>
Date: Feb 25, 2015 4:49 PM
Subject: RE: Senior Design Project- PRISM
To: "Brostow,Adam A." <BROSTOAA@airproducts.com>, "sandhya526@gmail.com" <sandhya526@gmail.com>
Cc:

Adam / Sandhya,

I would say that a feed gas with only 17mol% H2 is not a very high-value feed stream for a membrane system. Membranes are good when the feed gas is already at pressure, for feed streams that are not this large, and for feed gas that contains a higher concentration of the gas that you are trying to recover. I ran the #'s through our membrane screening tool. ROUGH estimates:

- Feed gas 600 psig
- Permeate 100 psig
- 17 mol% H2 w/ 3.7mol% CO2
- 113,200 lbmol/hr = 1031 MMSCFD feed flow

- Targeting 85% H2 recovery, permeate purity is 44mol%, rough cost estimate is $180MM (for membrane unit only, no feed compression).
- Targeting 50% H2 recovery, permeate purity is 55mol%, rough cost estimate $70MM (excludes feed compression).

I ran this separation past someone else within Air Products. Her recommendation was to process the feed gas stream in a cryogenic purification system. Take crude H2 off of the cryo unit to a PSA to make high purity H2. Would need to compress feed gas to about 350 psig. End up with a variety of fuel streams.

Hope this helps…

Regards,
Karin

From: Brostow,Adam A.
Sent: Wednesday, February 25, 2015 10:39 AM
To: Fair,Karin Aurora
Subject: FW: Senior Design Project- PRISM

FYI
Can they get it?

From: Brostow,Adam A.
Sent: Wednesday, February 25, 2015 10:02 AM
To: 'Sandhya Thiyagarajan'
Subject: RE: Senior Design Project- PRISM

Sandhya,

I don't know if Karin communicated it to you but you can't get 99.9% w/ a membrane. The web site says:

These systems have been designed to recover about 80% of the hydrogen at 99% purity from purge streams which contain up to 85% hydrogen purity.

Can you live w/ 99%?

You can look at a different purification technology or a membrane followed by another a final purification step.

Adam

From: Sandhya Thiyagarajan [mailto:sandhya526@gmail.com]
Sent: Tuesday, February 24, 2015 2:50 PM
To: Brostow,Adam A.
Subject: Re: Senior Design Project- PRISM

Adam,

The feed pressure for the stream is around 43 psia, but we can adjust that if need be (I think it's better to have a higher pressure to increase the driving force for the separation?). We are completely flexible on the permeate pressure, but we would like to recover hydrogen ~99.9% purity so that it can be directly sold. We are also recycling the other products besides hydrogen back into a reactor so we want minimal hydrogen left in the membrane.

Sincerely,
Sandhya